Quantum Rod Enhancement Films for Modern LCDs

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ABSTRACT

Quantum rod films, comprising the aligned quantum rods, emits polarized light that could potentially improve the efficiency of the LCD. In this talk, we will discuss about the High-quality alignment of the QRs showing a high polarization ratio for the PL. We developed these QREF containing red and green QRs, in the same films, for their application in LCD backlights. These films offer wider color gamut and almost two times higher optical efficiency (i.e. ~7.8%) for the conventional LCDs.

1 INTRODUCTION

Semiconductor quantum rods (QRs) due to their unique shape dependent emission properties have been a center of attraction since the last decade [1-6]. These materials not only exhibit the quantum confinement effect due to their size but also show polarized photoluminescence properties. This polarized emission appears due to the fine structure splitting of 1D ground exciton state [1-4]. Quantum rod enhancement film (QREF) has potential application in the backlight of LCDs due to polarized emission which enhances the optical efficiency, due to high transmission of polarized light from QREF through polarizer [5-10]. Conventional unpolarized backlights and quantum dot enhancement film can achieve an optical efficiency of 4.8% for LCDs, while the polarized emission from QREF can give as high as 7.9% of the optical efficiency. The film uniformity and high alignment quality for the QRs in the QREF are most important prerequisites for their application for LCD backlights. Numerous techniques have been explored to align QRs, however, a uniform large-size film with high polarization properties is still a challenge [7-10]. Mechanical rubbing provides rather low polarization ratio ~3.5 due to the poor control of the in-plane QR alignment [7]. Films realized through the polymer stretching achieved higher polarization ratio (~5.6:1), but often show non-uniform emission due to non-uniform stress distribution in polymeric film [9]. Electrospinning [10] helps to achieve good alignment of QRs in fibers with high degree of polarization calculated as $((I_{\parallel} - I_{\perp})/(I_{\parallel}+I_{\perp}))$ and equal to approximately ~0.6; however, the complicated process of preparing films from such fibers is an issue for using this method for the large-size QREF fabrication. Recently, photo-alignment technology, developed by our group has shown high order QR alignment with the assistance of liquid crystal monomer (LCM) using the spin-coating technique. The measured polarization ratio of the emitted light is obtained 7.8:1 [11]. Though, the spin coating cannot be employed for the uniform large area thick films (in □m range) deposition to match the LCD brightness requirement. Non-contact printing techniques offer the possibility of achieving thicker films with a great uniformity, and therefore, have been well studied in the sensorics and electronics, providing cost-effective routes for processing various nanomaterials[17],[21].the Inkjet printing has been studied widely to print different nanomaterials [19], [21]. The inkjet printing can be applied to different surfaces by modifying the ink properties; particularly with low viscosity inks. Thus, we developed the inkjet printing method for preparing QR films.

2 EXPERIMENTAL

A. Photoalignment Technique

To study the polarization properties of emission from the aligned QRs, we have used photoalignment technique. The sulfonic azo dye SD1 has been used as a commanding layer for alignment purpose [9]. The SD1 solution is prepared in dimethylformamide in 2wt% of concentration. The SD1 is coated on substrate by spin coating with an average layer thickness of ~10nm. The SD1 coated substrate is then irradiated to polarized light of wavelength 405nm that generates a preferred alignment direction, by photo-reorientation of the chromophores, orthogonal to the polarization azimuth of the irradiating light.

B. Inkjet Printing

Fujifilm DMP 2850 inkjet printer has been used to print the QR enhancement film on to the photoaligned substrate. The printer comprises a piezoelectric diaphragm which can print with a resolution of 25□m. However, the actual resolution depends on different solvent properties like viscosity, surface tension, and evaporation rate and the surface energy of substrate which determine the spot size on substrate. These solvent parameters are also needed to optimize for proper jetting condition of printer and uniform film deposition on substrate. After optimizing the solvent parameters for the QR-LCM solution, we printed the QREF on to the photoaligned substrate. The LCM aligns in the direction of the alignment layer but aligns QRs perpendicular to the easy axis of the SD1 alignment. After the film coating, the LCM has been polymerized under UV light to stabilize the alignment of the film.

CdSe/CdxZn1-xS core/shell QRs has been used for printing the emissive QREF. The Red and Green QRs have strong excitonic emission at 626 nm and 523 nm with a full width at half maxima (FWHM) ~ 33 nm and ~25nm respectively (see Fig. 1).

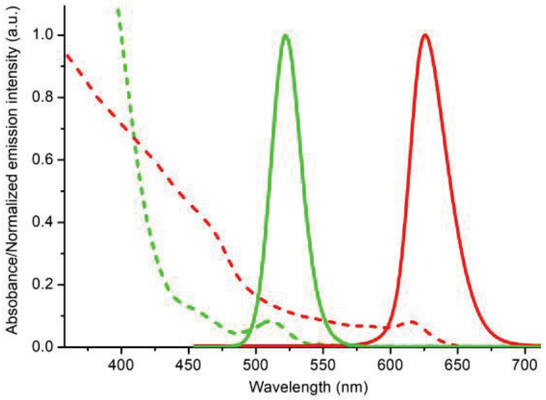


Figure 1. Absorbance (dashed lines) and emission profile (solid lines) for red and green QRs.

C. QREF Polarization Properties Measurement

To measure the polarization properties of emission from QREF, a laser of 450 nm is used to irradiate the QREF films and a spectrometer (Ocean Optics, USB 4000) is used to detect the emission spectra using optical fiber. A programmable rotating polarizer stage is used to detect the variation in intensity of emission with rotation of polarizer axis. Complete optical setup is shown in Fig. 2.

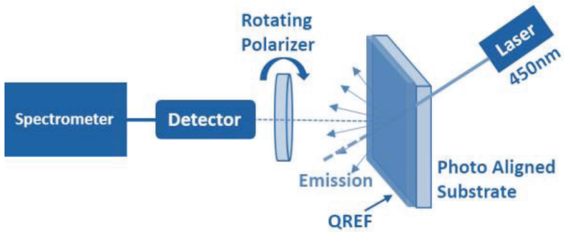


Figure 2. Optical setup for measuring polarization properties of QREF emission.

3 RESULTS AND DISCUSSION

To achieve the uniform film by inkjet printing; it is required to choose the correct drop spacing during printing. The droplets printed by individual nozzles expand on the substrate and merge to the other printed droplets. The expansion of drop, for the selected solvents, on the substrate is around 70-75μm. For large drop spacing (~70μm) the drops are not able to merge completely. As the drop spacing decreases, the printed lines start to merge and come closer to each other. However, complete and uniform merging is observed only for the drops spacing of 40μm, see Fig. 3(a).

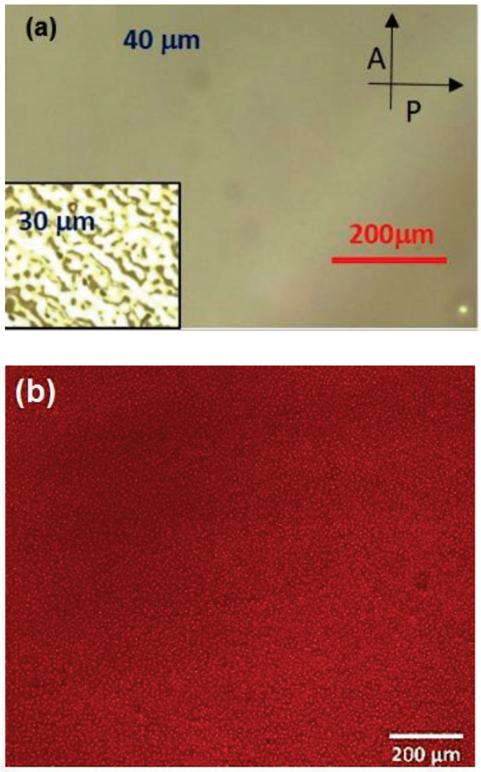


Figure 3 (a) POM image of Printed QR film with drop spacing of 40 μm. Inset shows the film with drop spacing of 30μm. (b) Fluorescence microscopy image of printed QR film with drop spacing of 40 m.

The color performance of LCDs depends on the backlight emission spectra and is thus to achieve a wide color gamut using QR films requires correct material combination for QR synthesis and proper size of QRs to achieve required wavelength and FWHM of emission from QRs. In this article, we have studied the performance of red and green QRs and their emission properties in film to fabricate QREF backlight to achieve wide color gamut for LCD with high polarization ratio and improved optical efficiency. Inkjet printing method has been developed to get multilayer uniform QREF, aligned on top of photoaligned substrate under assistance of LCM.

To check the uniformity of QR distribution in printed films, the fluorescence microscopy has been performed for different films shown in Fig. 3. It can be observed for the printed film with 40μm drop spacing QR are homogeneously distributed (Fig. (3(b)). Thus, it confirms the role of drop spacing for printing uniform film with uniform distribution of QRs in film.

As QRs show polarized emission thus the polarization ratio of QREF films were measured using the optical setup shown in Fig 2.Variation of emission intensity with polarizer axis angle for red QR film is shown in Fig. 4. It shows the good agreement with the Malus's law given by,

$$I(\theta) = (I_{max} - I_{min})\cos^2\theta + I_{min}. \quad (1)$$

Here θ is the angle between the polarizer transmission axis and QR alignment. Polarization ratio is defined as the ratio ($I_{\parallel}/I_{\perp}$) of emission intensities when polarizer is placed parallel or perpendicular to the QRs alignment. Polarization ratio measured for the printed films with red and green rods is obtained as high as 7:1 and 4:1 respectively. This high polarized emission is observed due to the in-plane alignment of QRs in aligned LCP medium above SD1 alignment layer.

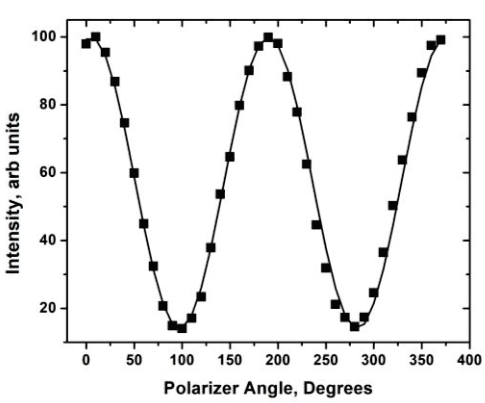
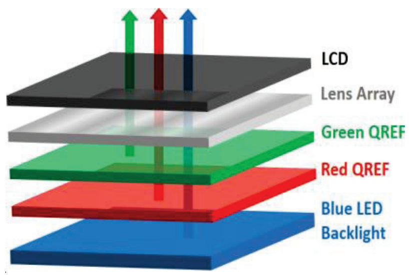


Figure 4. Intensity of red QR film with polarizer axis rotation angle providing a polarization ratio of 7:1. Solid line shows the fitting of data with Malus's law.

QRs exhibit dipolar emission with highly polarized emission along long axis compared to short axis. If the QRs are not aligned, then it behaves as an unpolarized light source due to the random orientation of QR long axis. When QRs are aligned unidirectional; in-plane to substrate surface then the polarized emission along the long axis become prominent and show high polarized emission from the aligned QREF. Showing a polarization ratio of 7:1, a single layer of QREF show insufficient brightness and white balance, and therefore, we used multiple layer printing. For multiple layer printing, each layer is polymerized before printing the next QREF layer.



(a)

(b)

Figure 5. (a) Schematic of arrangement of different layer of QREF backlight unit with LCD. (b) LCD with QREF backlight unit.

After printing red and green QR film with optimized thickness, the two QR films are sealed and assembled together with the blue LED backlight of wavelength 450 nm. The lens array has been used to couple the divergent light from backlight to LCD. The Schematic of backlight unit is shown in Fig. 5. The intensity of QREF backlight is measured ~7200 nits, which becomes ~561nits after the LCD panel showing an optical efficiency of ~7.8%. The LCD demo with QREF backlight unit is shon in Fig. 8(b).

4 CONCLUSION

In conclusion, polarized emissive quantum rods enhancement films have been prepared using inkjet printing on the photoaligned substrate. Optimized ink and drop spacing for ink-jet printing show uniform film with uniform distribution of quantum rods. The photoalignment technique show highly ordered quantum rods alignment in liquid crystal polymer matrix that results in High polarization ratio for the quantum rod enhancement films. Afterward, we used these films as a LCD backlight that helps to boost the optical efficiency of the LCD to 7.8%, which is almost twice higher than the conventional LCDs. Furthermore, the quantum rods enhancement films backlight unit shows the wider color gamut. Thus, the fabricated quantum rods enhancement films provide highly saturated colors and highly efficient displays solutions.

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