Highly Stable Quantum Rod White LED with Optimal Luminous Efficacy and Color Performance

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ABSTRACT

Quantum rods (QRs) have shown great potential for modern displays owing to their polarized emission and high light coupling coefficients [1]. Compare to three main architectures used for the quantum materials applications in the liquid crystal display (LCD) backlights, the on-chip configuration [2], having quantum material on the top of the LED chip, is the most desirable architecture. In this case, the display requires the least amount of quantum materials. The on-chip LED structure requires quantum material with thermally stable photoluminescence properties [3] and high efficacy. Here we have synthesized quantum rods of configuration CdSe/Zn$_x$Cd$_{1-x}$S, which show significantly better temperature stability in comparison to the conventional Cd based QRs. Additionally, the Cd concentration was reduced, which make it more environment-friendly QRs. Unlike general lighting applications, LCD uses the RGB color filter to reproduce color images, which requires QRs with narrow full width at half maximum (FWHM) for better color saturation. The proposed approach offers an ability to precisely tune the emission wavelength and maintain the narrow FWHM for the QRs. The fabricated QRs LED backlight shows the color triangle 90% of BT2020 color standards. The efficacy of designed QRLED is 112 lm/W [4], which is 26% higher than commercially available LEDs [5].

1. INTRODUCTION

Quantum materials like quantum dots (QDs) has interesting properties like tunable and narrower full wave at half max (FWHM) in visible wavelength compared with phosphor. It has been regarded as the most promising luminescent material and an ideal candidate for the color enhancement film, lighting and LED devices [6][7]. The distinct property of quantum rods arises from the ability of growing the special cores into rod-like shapes with large aspect ratios followed by the growth of a wide bandgap semiconductor shell. Efficient emission with polarized light can be achieved accompany with high light coupling coefficients. In this study, red and green QRs with configuration CdSe/Zn$_x$Cd$_{1-x}$S with efficient, stable and narrow band PL have been synthesized for LCD backlight application. To achieve highly saturated color gamut, it is highly desirable to achieve the down conversion photoluminescence material with narrow emission bandwidth as well as precisely tunable emission peak and high quantum yield. These are the most important metrics used in evaluating down-converters for displays. The narrower FWHM contributes to the better the color quality. CdSe/CdS Semiconductor quantum rod has great property among phosphor and InP quantum dots. Compared with CdSe/Zn$_x$Cd$_{1-x}$S, commercial Cd-free materials are InP based QDs shows that the FWHM of the emission is around 50nm for green and 65nm for red, which is not comparable to the QRs with FWHM around 25-35nm. Luminous efficacy refers to the ability of a light source to produce a meaningful response in the human eye, and it is the total luminous flux (in lumens) divided by the rated power (in watts) [8][9][10].

2. Results and discussion

Figure 1 shows how the photoluminescence intensity changes as a function of temperature for both initial QRs and Zn modified green and red QRs. The Zn-modified QRs show excellent thermal stability up to 120°C. The QRs of configuration CdSe/Zn$_x$Cd$_{1-x}$S with tunable emission, which can cover the whole visible range with high color purity. By engineering the QR structure, both rods with a Zn-modified shell show excellent thermal stability.

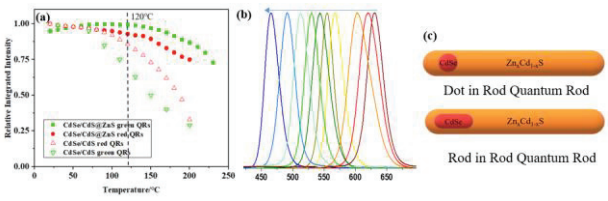

Fig 1: a) Temperature dependence of Luminescence intensity of Zn-modified QRs and initial CdSe/CdS QRs. b and c) Obtained different structure QRs with full visible color range

There are three main structures for QD/QR integration approaches in LCD. The quantum dot enhancement film (QDEF) is predominated and has been into mass production, quantum rod enhancement film (QREF) [11] can improve the polarization efficiency of the LCD polarizers and further improve the optical efficiency of the LCD. The edge optic has largely become obsolete and the transition from Cd based material towards Cd-free/less QDs is in highly essential. In recent years, white LED has replaced the CCFL in LCD backlight application, both red and green core-shell rod-like

QD/QRs with high efficacy, high thermal stability, and narrow-band PL are highly demanded in the market.

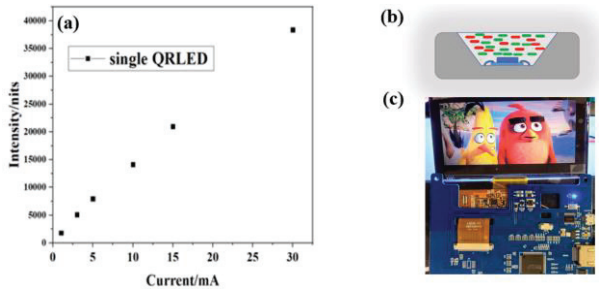

Fig 2: a) Current dependence of intensity b) Schematic diagram of QRLED c) Display prototype of a 4.7-inch IPS panel equipped with 15 QRLEDs backlight

The mixture of red and green QRs with a controlled 1:10 mass ratio is dispersed in the silicone glue on the top of the blue LED die with a peak wavelength at 450nm, followed by curing. This implementation strategy as QRs is placed closed to the LED source, going from film to edge optics to on-chip structure requires red and green QRs to be stable against the much higher temperature and excitation flux. We have fabricated an LCD backlight of the white light source (QRLED) using 15 commercial blue LEDs (450 nm) equipped with the light guide plate (LGP), reflector, diffuser, and mixture of red and green Zn-modified QRs with silicone glue as on-chip down-convertors. The QRLED backlight with 112lm/W efficacy can achieve 90% BT2020 color standard.

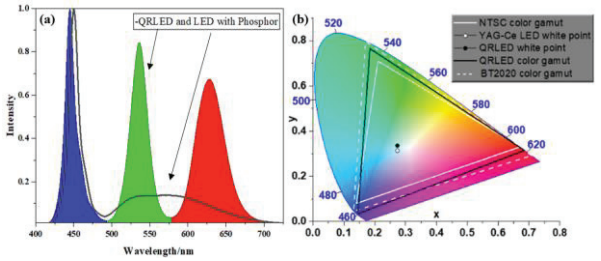

Fig 3: a) Spectrum of QRLED backlight and normal LED backlight. b) CIE chromaticity diagrams of YAG-Ce white LED and QRLED. QRLED backlight shows the color triangle 90% of BT2020 color standards

3. Conclusion

In this study, we disclosed red and green core-shell quantum rods of configuration $CdSe/Zn_xCd_{1-x}S$ with high efficiency (112 lm/W), high thermal stability (up to 120ºC). Later we deploy these down-converting photo-luminescence material in the on-chip LED configuration for the LCD backlight unit. Later we deploy these down-converting photo-luminescence material in the on-chip LED configuration for the LCD backlight unit. The LCD equipped with these LED backlight unit show much wider color gamut covering 122% of NTSC or 90% of BT2020 color standards. Additionally, higher efficacy, even at higher temperatures, is very appealing for the LCDs. Thus, with higher LCD efficiency, color gamut, and higher thermal stability, these white QRLEDs are perfectly suitable for modern LCD backlight units. Furthermore, the efficacy of 112 lm/W is around 25% higher than the LED available in the lighting market (~89 lm/W). Thus, the proposed QRLED is also good for the lighting application.

4. Acknowledgment

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