

Tri-package White LEDs as a High-Color-Quality Lighting Source with Cd-free Quantum Dots

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Extended Abstract

In this study, we fabricated high-color-quality tri-package white-light-emitting diodes (WLEDs) using an InGaN blue LED and broadband-emitting green (G) or red (R) quantum dot (QD)-based down-converted LEDs (DC-LEDs) to realize high-color-quality WLEDs with various correlated color temperatures (CCTs) from cool white to warm white. To evaluate the color qualities, we adopted a color rendering index (CRI, Ra) and the TM-30-2015 color fidelity index (CFI, Rf), a color gamut index (CGI, Rg) and a color vector graph which is an improved version for color metrics to overcome the problems associated with the CRI [1, 2]. The new color metrics of TM-30-2015 were developed by the Illuminating Engineering Society of North America (IES).

To fabricate monochromatic G and R down-converted LEDs, we synthesized Cd-free G and R QDs, broadband-emission I-III-VI₂-based AgIn₅S₈/ZnS for G and CuInS₂/ZnS for R by a colloidal hot-injection method. The AgIn₅S₈/ZnS and CuInS₂ and ZnS QDs showed corresponding peak wavelengths of 514 nm and 589 nm and broadband full-width-at-half-maximum (FWHM) values of 97 nm and 115 nm due to donor-acceptor recombinations [3]. They also showed photoluminescent quantum yields (PLQYs) of 75% and 85%, respectively.

To realize tri-package WLEDs, we fabricated monochromatic G and R QD-based DC-LEDs using a long-wavelength pass-dichroic filter (LPDF), which reflects blue light to prevent color mixing from the excitation source of the blue LED and transmit G and R QD emission light [4]. To fabricate monochromatic G or R QD-based DC-LEDs, G and R QDs were mixed with Si-binder and put into an InGaN blue LED cup as an excitation source. Subsequently, LPDF was simply capped onto the LED cup to realize the monochromatic G or R QD-based DC-LEDs. The G and R QD-based DC-LEDs show peak wavelengths of 533 nm and 639 nm and luminous efficacy (LE) rates of 102 lm/W and 42 lm/W, respectively. The peak wavelengths of the QD-based DC-LEDs were red-shifted due to the agglomeration of QDs which occurred while mixing them with the Si-binder [5].

Finally, the InGaN blue LEDs (peak-wavelength of 448 nm, FWHM of 22 nm and LE of 18 lm/W) and G, R QD-based DC-LEDs were arranged in a triangular shape and applied separately with a total current of 180 mA at various CCTs of 10,000 K, 6,500 K, 5,000 K, 3,500 K, and 2,700 K. When realizing cool to neutral white (10,000 K ~ 5,000 K), the portions of the applied current of the blue LED and the G QD-based DC-LEDs are higher than that of the R QD-based DC-LED. On the other hand, when realizing warm white (3,500 K and 2,700 K), the portion of the applied current of the R QD-based DC-LED is higher than that of the B LED or the G QD-based DC-LED. For this reason, the LEs of the WLEDs show relatively low values with warm white of 2,700 K (41 lm/W) compared to cool white at 10,000 K (52 lm/W) due to the low LE of the R QD-based DC-LED. The color qualities of WLEDs show high values (CRI: 86~94, CFI: 79~94 and CGI: 103~106) from 10,000 K to 2,700 K. These results indicate that the tri-package WLED can be a good candidate for high-color-quality white lighting with various CCTs.

References

- [1] D. A. P. T. Fini, K. W. Houser, Y. Ohno, M. P. Royer, K. A. G. Smet, M. Wei, L. Whitehead, "Development of the IES method for evaluating the color rendition of light sources," *Opt. Express*, vol. 23, pp. 15888–15906, 2015.
- [2] M. P. Royer, "IES TM-30-15 Is Approved-Now What? Moving Forward with New Color Rendition Measures," *Leukos*, vol. 12, pp. 3–5, 2016.

- [3] N. S. Han, H. C. Yoon, S. Jeong, J. H. Oh, S. M. Park, Y. R. Do, and J. K. Song, "Origin of highly efficient photoluminescence in AgIn_5S_8 nanoparticles," *Nanoscale*, vol. 9, pp. 10285-10291, 2017.
- [4] J. R. Oh, S.-H. Cho, H. K. Park, J. H. Oh, Y.-H. Lee, Y. R. Do, "Full down-conversion of amber-emitting phosphor-converted light-emitting diodes with powder phosphor and a long-wave pass filter," *Opt. Express*, vol. 18, pp. 11063-11072, 2010.
- [5] M. Ko, H. C. Yoon, H. Yoo, J. H. Oh, H. Yang, Y. R. Do, "Highly efficient green Zn-Ag-In-S/Zn-In-S/ZnS QDs by a strong exothermic reaction for down-converted green and tripackage white LEDs," *Adv. Func. Mater.*, vol. 27, pp. 1602638, 2017.