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The thermal stability performances of the color rendering index of white light emitting diodes with the red quantum dots encapsulation

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ABSTRACT

Red phosphors are the traditional material used to improve the color rendering index (CRI) of white light emitting diode (WLEDs). In this paper, red quantum dots (QDs) were fabricated and coated on the blue LED chip to replace the red phosphors. By comparing the thermal performances of the CRI for the two WLEDs, we found that WLEDs with the encapsulation of yellow phosphors and red QDs exhibited higher CRI and lower sensitivity to temperature than those with the encapsulation of yellow and red phosphors. The CRI of WLEDs with yellow phosphors and red QDs was 90.9, and its range ability was only 0.3 when the environment temperature changed from 25 °C to 100 °C, while the CRI of WLEDs with yellow and red phosphors was as low as 81.8, and the change of CRI was 2.2 during the same temperature variation.

1. Introduction

In the 1990s, Nichia Co. successfully manufactured white light emitting diodes (WLEDs) with blue chips and yellow yttrium aluminum garnet (YAG) phosphors [1]. After decades of development, WLEDs have attracted much attention in recent years because of their widespread utilization for displays and lighting. Compared with traditional lighting sources, they exhibit some advantages such as lower energy consumption, smaller form factor, longer lifetime, lower driving voltage, faster response time, and higher environmental friendliness [2,3]. However, the present WLEDs coated only with YAG cannot fit the requirements of advanced illumination because of insufficient color rendering index (CRI) and low luminous efficiencies. And inappropriate lighting conditions were shown to upset body chemistry, which was regulated by melatonin, and lead to deleterious health effects [4–6]. The CRI was a key factor which was related to the lighting condition.

The reason for WLEDs with low CRI was the deficiency in red spectral components [7]. There were some approaches to complement the red part of spectrum, such as the trichromatic and tetrachromatic LEDs [8,9], and the mixing of multi-color materials for encapsulation based on a blue LED chip to improve the color quality [10–13], and color performance can also be improved by doping or nanoparticles hybrid [14].

Additionally, significant progress has also been made toward warm WLEDs with quantum dots (QDs) and yellow phosphors. Among the warm WLEDs mentioned above, hybridization of $Ca_2BO_3Cl:Eu^{2+}$ yellow phosphors with CdSe/ZnS nanocrystals contributed to increase white spectrum of LED and generated the warm color temperature (4055 K) with high CRI (83.9) of white light [15]. Aboulaich et al. concluded that YAG:Ce nanophosphor CIS/ZnS QDs with blue LED displayed higher CRI of about 84 and warm white light with a correlated color temperature of 3000 K at 350 mA [16]. Although numerous studies have incorporated QDs with LEDs to improve the CRI value, and some studies [17,18] have investigated the effect of temperature on CdSe/ZnS QDs in LED. Few researches focus on the stable thermal behavior of CRI in QDs LED devices.

In this paper, we have fabricated warm WLEDs with splendid CRI by the introduction of red QDs into the encapsulation. Experimental results demonstrated that LEDs with the encapsulation of red phosphors or red QDs had better CRI than those with the encapsulation of single yellow phosphors. Moreover, WLEDs with red QDs exhibited superior thermal stability of CRI than those of WLEDs with red phosphors.

2. Materials and methods

2.1. Materials and instruments

The silicone resin (OE-6550A and OE-6550B), yellow phosphors (YAG-04), red phosphors (ER6436), blue-light chips (EZ900), and

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silver adhesive (M705-S101-S4) were purchased from Dow Corning Toray Co. Ltd, Intematix Photonics (SZ) Co. Ltd, Cree and SMIC, respectively. Furthermore, the electroluminescent properties, CRI, photoluminescence (PL) properties and temperature-dependent properties of LEDs were recorded by Spektron coating integrating sphere and fluorescence spectrophotometer (HITACHI F4500), respectively. Additionally, the size and the crystallinity of the QDs were measured by field-emission transmission electron microscope (JEM-2100F). The PL spectrum of the QDs was measured by HITACHI U-3900H ultraviolet–visible spectrophotometer and FLSP920 Transient and steady state fluorescence spectrometer at room temperature.

2.2. Synthesis of QD

Cadmium oxide (CdO, 99.99%), zinc acetate (99.9%, powder), selenium powder (Se, 99.99%), sulfur powder (S, 99.9%), oleic acid (OA, 90%), trioctylphosphine (TOP, 90%), 1-octadecene (ODE, 90%) were from commercial purchase.

As a typical synthetic procedure, 1 mmol Cadmium oxide, 3 mmol zinc acetate, 17.6 mmol oleic acid and 20 mL 1-octadecene were placed in a 100 mL round flask. The mixture was degassed under 100 mTorr pressured for 15 min, then filled with N_2 gas, and further heated to 310 °C. At this temperature, 0.4 mmol of Se powder and 2.3 mmol of S powder both dissolved in 3 mL of TOP were quickly injected into the reaction flask. After the injection, the temperature of the reaction flask was set to 280 °C to promote the growth of QDs for 30 min, and it was then cooled to room temperature to stop the growth. QDs were purified by adding 20 mL of chloroform and an excess amount of acetone, they were then dispersed in toluene.

2.3. Fabrication of WLED

The blue-light chip was put on the substrate with reflow soldering and the gold wire was bonded with the blue-light chip and substrate. Afterward, the yellow phosphors were mixed evenly into the silicone resin (yellow phosphors/6550A/6550B = 40/100/100;

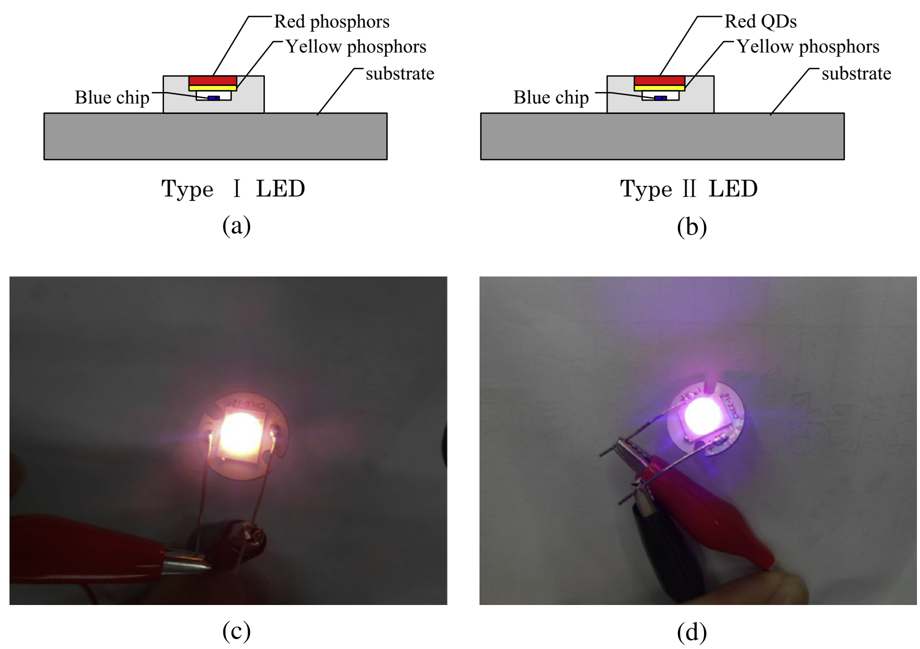

Fig. 1. (a) Structures of WLED with the encapsulation of red phosphors and yellow phosphors; (b) structures of WLED with the encapsulation of red QDs and yellow phosphors; (c) type I LED at 350 mA; (d) type II LED at 350 mA.

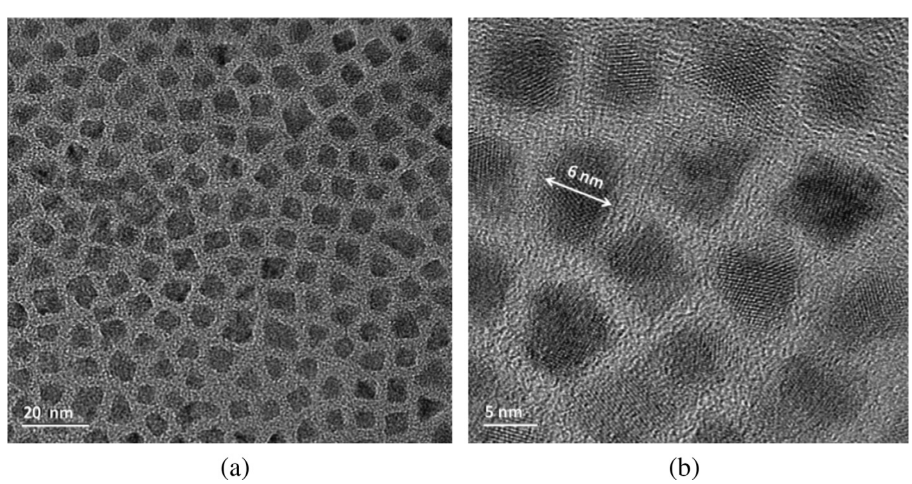

Fig. 2. (a) TEM images of CdSe/ZnS core shell QDs. (b) A high resolution TEM image of QSs.