White light-emitting diodes (WLEDs) have the potential to replace traditional incandescent and fluorescent lamps for their special characteristics, namely, long lifetimes, savings of energy, and environmental protection\(^{1-3}\). WLEDs based on a blue LED plus yellow phosphor (YAG) is widely used and commercially available. However, this kind of WLED has several disadvantages of blue/yellow color separation and poor color rendering index (CRI) property caused by lack of red component in the spectrum. Recently, quantum dots (QDs) of II-VI semiconductor that passivates the surface states of the semiconductor have drawn significant attention over the past decade\(^{4-8}\). Semiconductor QDs, which have a broad absorption band, can be effectively excited by ultraviolet (UV) or visible light basically. In particular, CdSe QDs have been regarded as promising materials for white LEDs due to their size-dependent emission tunability and high quantum yield. The CdSe cores can be chemically synthesized with a surrounding shell of a wider band-gap semiconductor, and have shown significant increase in the QD photoluminescence quantum efficiency. In this letter, QD LEDs are fabricated by using a monolayer of colloidal CdSe/ZnS nanocrystals as the light-emitting layer.

The CdSe/ZnS QDs were synthesized by the following steps. The Cd-precursor was prepared by dissolving 5 mmol of cadmium oxide in a mixture of 25 mmol of lauric acid and 8 mmol of hexadecylamine at 300 °C under argon flow. The Se-precursor was prepared by dissolving 5 mmol of Se-powder in 6.5 mmol of trioctylphosphine oxide hybrid. The CdSe/ZnS QDs show high photoluminescence efficiency, with a quantum yield greater than 48% and size-tunable emission wavelengths ranging from 500 to 620 nm. A diode that emits white light with color coordinates of (0.311, 0.321) and luminous efficiency of 46.7 lm/W at 20 mA, as standardized by the Commission Internationale de L’Eclairage or International Commission on Illumination, is fabricated by combing a blue indium-gallium nitride (InGaN) chip with multi-CdSe/ZnS QDs.

Figure 1 shows the transmission electron micrograph (TEM) of a typical sample containing CdSe/ZnS QDs. The average size of the CdSe/ZnS QD sample is 5.5 nm, and the QD has a spherical shape. Figure 2 shows the absorption spectra of the CdSe QDs before and after coating with different shells. The CdSe QDs can absorb light efficiently from the near-ultraviolet to the blue (400–520 nm) regions of the spectrum. For the QDs of CdSe, CdSe/CdS, and CdSe/ZnS, the absorption peaks are found at 450, 445, and 444 nm, respectively. It can be seen that the excitation wavelength of the CdSe/CdS is close to the emission wavelength (460 nm) of the InGaN LED chip. However, considering the environmental protection, we used the ZnS as the shell of the CdSe QDs, though its excitation intensity is slightly lower than that of the CdSe/CdS. Figure 3 shows the PL spectra of the CdSe/ZnS QDs.

White light-emitting diode based on Multi-core/shell CdSe/ZnS quantum dots

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Core/shell CdSe/ZnS quantum dots (QDs) are synthesized by thermal deposition using cadmium oxide and selenium as precursors for a hot lauric acid and hexadecylamine trioctylphosphine oxide hybrid. The CdSe/ZnS QDs were then obtained. By appropriately collocating multi-different kind size of QDs on the indium-gallium nitride (InGaN) chip, a WLED, containing a blue InGaN chip, along with green-, yellow-, orange-, and red-emitting QDs, was fabricated.

To increase the stability of the CdSe QDs, shells such as CdS, ZnS or shell/shell CdS/ZnS were used. Figure 2 shows the absorption spectra of the CdSe QDs before and after coating with different shells. The CdSe QDs can absorb light efficiently from the near-ultraviolet to the blue (400–520 nm) regions of the spectrum. For the QDs of CdSe, CdSe/CdS, and CdSe/ZnS, the absorption peaks are found at 450, 445, and 444 nm, respectively. It can be seen that the excitation wavelength of the CdSe/CdS is close to the emission wavelength (460 nm) of the InGaN LED chip. However, considering the environmental protection, we used the ZnS as the shell of the CdSe QDs, though it’s excitation intensity is slightly lower than that of the CdSe/CdS. Figure 3 shows the PL spectra of the CdSe/ZnS QDs.
Fig. 2. Excitation spectra of CdSe QDs before and after coating with different shells.

Fig. 3. PL spectra of CdSe/ZnS QDs of various sizes.

Fig. 4. Electroluminescence spectra of a combination of green ($\lambda_{PL} = 520$ nm), yellow ($\lambda_{PL} = 558$ nm), orange ($\lambda_{PL} = 590$ nm), and red ($\lambda_{PL} = 620$ nm) QDs with blue LED ($\lambda_{EL} = 450$ nm) at various currents at room temperature.

Fig. 5. Color coordinates of QDs WLED and standard illuminants A, C, D50, D55, D65, and D75 in the CIE 1931 chromaticity diagram.

of emitted photons from each QDs layer going through the subsequent QDs layers. It can be seen that the green, yellow, orange, and red QDs are stable with the increasing of the forward bias from 20 to 60 mA. And this WLED showed a luminous efficiency of 46.7 lm/W under the forward bias of 20 mA.

Figure 5 shows the color coordinates of InGaN/QDs WLED, measured under a forward bias of 20 mA. Compared with the six standard illuminants A, C, D50, D55, D65, and D75, the Commission Internationale de L’Eclairage (CIE) color coordinates of the light emitted by the InGaN-based QD-containing WLEDs were (0.311, 0.321) and the CRI was 89, which is larger than the CRI of YAG:Ce WLEDs. And this WLED showed a luminous efficiency of 46.7 lm/W under the forward bias of 20 mA.

In conclusion, CdSe/ZnS QDs, with a quantum yield of approximately 48% and size-tunable emission wavelengths ranging from 500 to 620 nm, are fabricated within a novel WLED. The WLED (a blue InGaN chip, with green-, yellow-, orange-, and red-emitting CdSe/ZnS QDs) yields emits white light with CIE coordinates of (0.311, 0.321) and CRI of 89.

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