Supporting information

The Application of $Zn_{0.8}Cd_{0.2}S$ Nanocrystals in White Light Emitting Diodes Devices

Ya-Ching Chen,[a] Cyuan-Bin Siao,[a,b] Hong-Shuo Chen,[a] Kuan-Wen Wang,*[a] and Shu-Ru Chung*[b]

*To whom correspondence should be addressed,
E-mail: kuanwen.wang@gmail.com
Fax: 886-3-2805034, Tel: 886-3-4227151 ext 34906
Current address: Institute of Materials Science and Engineering, National Central University, No.300, Jhongda Rd., Taoyuan 32001, Taiwan.

E-mail: srchung@nfu.edu.tw
Fax: +886-5-6361981; Tel: 886-5-6315483
Current address: Department of Materials Science and Engineering, National Formosa University, No. 64 Wunhua Rd., 63201, Yunlin, Taiwan.

1. Experimental Procedure

1.1 Preparation of $Zn_{0.8}Cd_{0.2}S$ NCs

Cadmium oxide (CdO, 99.998 %) and stearic acid (SA, 99 %) were obtained by Alfa Aesar. Zinc oxide (ZnO, 99.999 %), sulfur powder (S, 99.98 %), decene (DE, 94%), tetradecene (TDE, 92%), octadecene (ODE, 90 %), hexadecylamine (HDA, 90 %), and trioctylphosphine oxide (TOPO, 90 %) were purchased from Sigma-Aldrich. Hexane (99.7 %) and methanol (99 %) were gotten from Mallinckrodt Chemicals. All chemicals were used as received without purification.

The colloidal ternary semiconductor $Zn_{0.8}Cd_{0.2}S$ NCs were prepared by thermal pyrolyzed organometallic route as reported previously.[27] Briefly, ZnO and CdO were mixed with SA in a three-necked flask and the mixture was heated to 230 ^{o}C under Ar flow. Then the solution was cooled down to room temperature, and a white solid precipitate was obtained. The TOPO and HDA were added into a three-necked flask and stirred together under Ar flow, and then the solid precipitate was reheated up to 320 ^{o}C. At this temperature, S-DE, S-TDE or S-ODE precursors, were rapidly injected into a three-neck flask and reacted for 10, 30 or 60 minutes. The mixed solution was swiftly cooled down to 150 ^{o}C to stop reaction. After purification, the precipitate was dissolved and dispersed in hexane to remove unreacted reagents for further measurement. The $Zn_{0.8}Cd_{0.2}S$ NCs are named as ZnCdS for short.

1.2 Characterization of NCs

The optical properties of the prepared NCs were measured by fluorescence spectrophotometer (FL, Hitachi F-7000) and ultraviolet-visible spectrometer (UV-Vis, Jasco V-670 spectrometer). Relative quantum yields (QYs) of the NCs were determined by comparing the area under the curve of FL emission with that of fluorescent dye (Rhodamine 101 in ethanol). The concentration of the QDs and the

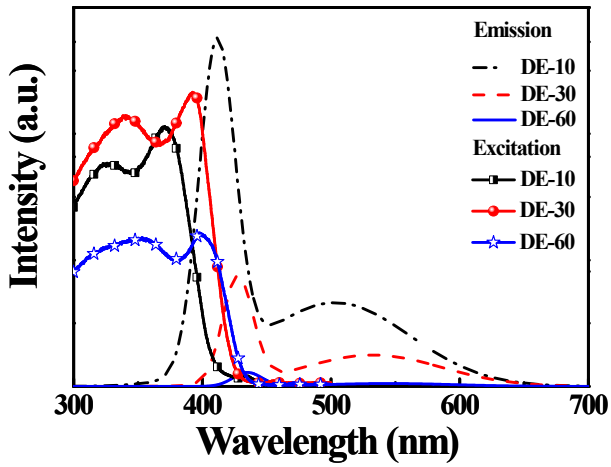
Rhodamine 101 dye were adjusted to the same optical density at the excitation wavelength. The standard QY of Rhodamine 101 is 98 %. The QYs of sample was calculated by the following equation:

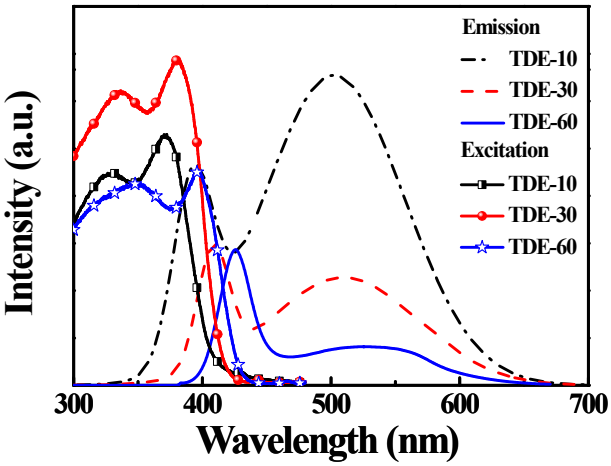
$$QY_s = QY_r \frac{F_s}{F_r} \frac{A_r}{A_s} \frac{n_s^2}{n_r^2}$$

where F_s and F_r are the integrated fluorescence emissions of the sample and the reference, respectively, A_s and A_r are the absorbances at the excitation wavelength of the sample and the reference, respectively, n_s and n_r are the solvent refractive index of the sample and the reference, respectively, and QY_s and QY_r are the QY of the sample and the reference, respectively.

1.3 Preparations of WLED devices

The mixtures of various ZnCdS NCs and transparent UV resin with the NCs weight ratios of 10.0 and 50.0 wt. % were prepared, and applied for the WLED fabrication. WLEDs were fabricated by using 3020-surface-mounted device (SMD)-typed InGaN/GaN-based near-UV emitting LEDs with 13 mil. The UV LED die (13 mil) with type FD130A-UV were provided by Formosa Epitaxy incorporation (FOREPI) (merged by EPIXTAR in 2015). The UV-LED die is through die attachment and wire bonding on 3020 reflect cup to form UV-LED chip, prepared by LEXTAR. In this study, two different encapsulation methods (convert and remote) were used. Convert type devices were prepared by directly dropping the mixture of QDs and resin on the LED chip. Remote type devices were formed by the upper layer with the mixture of QDs and resin and the bottom layer with the pure resin on the LED chip. The mixture was cured by exposing under UV light for 3 minutes. The performance of devices was measured by integrating sphere (Isuzu Optics, ISM-360) under 20 mA applied current.





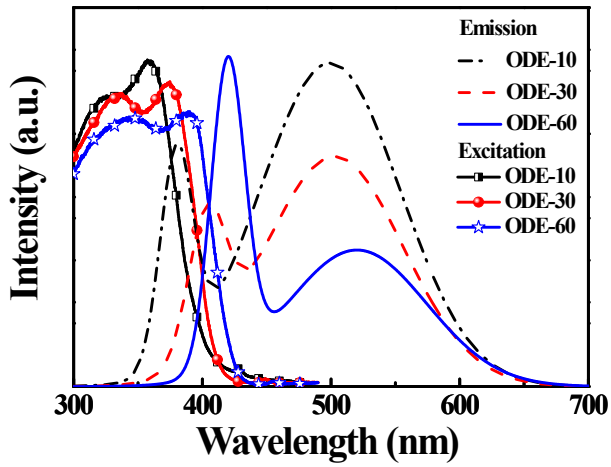


Figure S1 The FL excitation and emission spectra of various ZnCdS NCs

Table S1 The device properties of ZnCdS NCs-based WLEDs.

Sample	NCs content (wt. %)	CIE (x, y)	CRI	CCT (K)	Efficiency (lm/W)	QY (%)
DE-10	10	(0.19, 0.10)		NA		99.0
	50	(0.27, 0.24)	81	29427	2.73	
DE-30	10	(0.37, 0.32)	86	3947	3.31	50.4
	50	(0.39, 0.38)	81	3789	4.12	
DE-60	10	(0.40, 0.34)	87	3215	2.54	25.3
	50	(0.45, 0.43)	81	2997	2.92	
TDE-10	10	(0.17, 0.09)		NA		72.6
	50	(0.26, 0.24)	83	28234	3.37	
TDE-30	10	(0.29, 0.25)	75	13114	4.19	48.7
	50	(0.34, 0.31)	79	5178	4.34	
TDE-60	10	(0.38, 0.34)	86	3631	3.05	34.6
	50	(0.44, 0.42)	81	3085	3.30	
ODE-10	10	(0.17, 0.08)		NA		55.4
	50	(0.25, 0.20)				
ODE-30	10	(0.23, 0.17)		NA		38.7
	50	(0.32, 0.30)	82	6811	4.26	
ODE-60	10	(0.38, 0.34)	84	3718	3.41	36.2
	50	(0.43, 0.43)	80	3355	3.67	

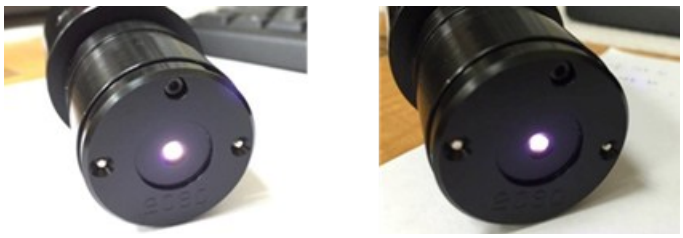


Figure S2 The photographs of the (left) as-prepared TDE-60 remote-type device and (right) the one after stability test.

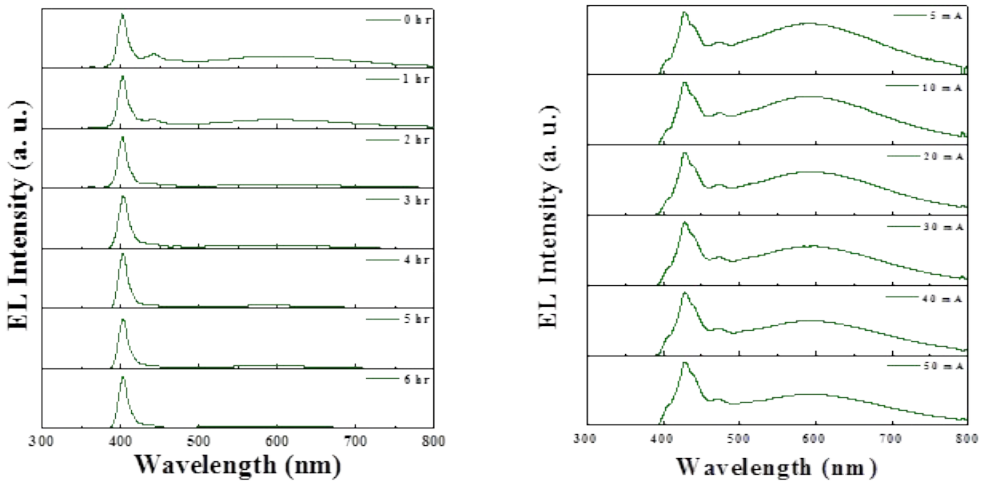


Figure S3 The EL spectra of TDE-60 remote-type device (left) during 20 hr stability test and (right) under 5-50 mA.

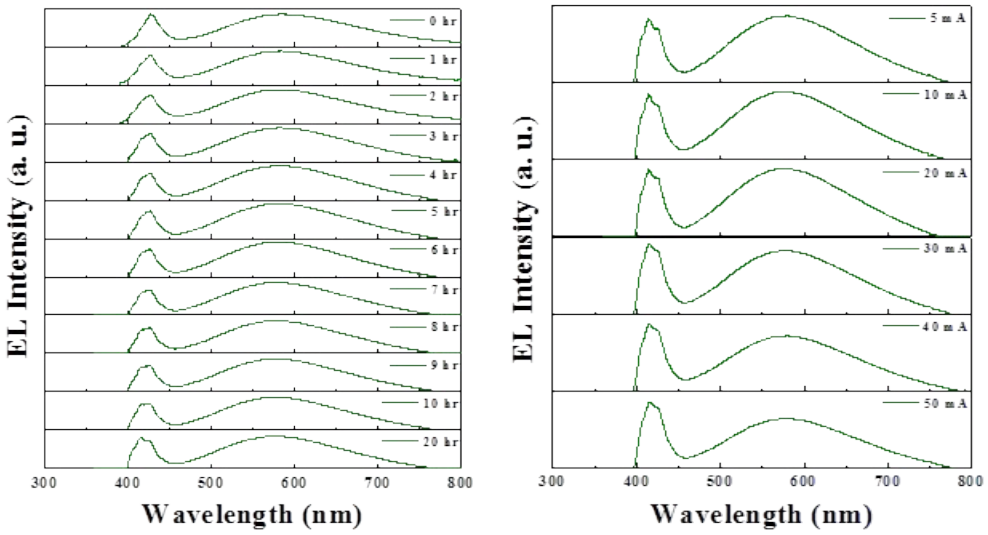


Figure S4 The EL spectra of ODE-30 convert-type device (left) during 20 hr stability test and (right) under 5-50 mA.