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Supporting Information

Ultrabroad-band, red sufficient solid white emission from carbon quantum dots aggregation for single component warm white light emitting diodes with a 91 high color rendering index

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Chemicals.

Guanidine carbonate, monopotassium phosphate and dichloride were purchased from Sun Chemical ＆Technology (Shanghai) company. All chemicals are analytical grade and used as received without further purification. Deionized water (DIW) was used throughout the experiments

Experimental Section

Synthesis of solid ultra-BWCQDs. The ultra-BWCQDs were synthesized by using solvothermal method. Guanidine carbonate (10 mg) and monopotassium phosphate (5 mg) were dispersed in methylene dichloride (10 mL), and the solution was then transferred to a poly (tetrafluoroethylene) (Teflon)-lined autoclave (25 mL) and heated at 170°C for 8 h. After the reaction, the reactor was cooled to room temperature naturally. The obtained solution was purified via dialysis against deionized water in a dialysis bag for 12h. Finally, the solid ultra-BWCQDs was obtained by drying aqueous solution at 70 ºC.

Synthesis of solid ultra-BWCQDs without P-doping

The solid ultra-BWCQDs without P-doped were synthesized using solvothermal method. Guanidine carbonate (20 mg) were dispersed in methylene dichloride (10 mL), and the solution was then transferred to a poly (tetrafluoroethylene) (Teflon)-lined autoclave (25 mL) and heated at 180° C for 8 h. After the reaction, the reactor was cooled to room temperature naturally. The obtained solution was purified via dialysis against deionized water in a dialysis bag. The QY of solid ultra-BWCQDs without P-doping are 7%, which is lower than the solid ultra-BWCQDs with P-doping

Characterization. A JEOL JEM 2100 transmission electron microscope (TEM) was used to investigate the morphologies of CQDs. X-ray diffraction (XRD) pattern was carried out by an X-ray diffraction using Cu Kα radiation (XRD,PANalytical X'Pert Pro MPD). XPS was performed with an ESCALab220i-XL electronspectrometer from VG Scientific using 300 W Al Kα radiation. The FT-IR spectra were measured using a Nicolet 380 spectrograph. NMR spectra were obtained by Bruker DRX500. Absorption spectra were recorded on UV-2600 spectrophotometry. The fluorescence spectra were measured on a PerkinElmer-LS55 luminescence spectrometer. Absolute quantum yield measurements were performed with a calibrated integrating sphere on a Varian FLR025 spectrometer. The photographs were taken with camera (Nikon, D7200) under UV light excited at 365 nm (UV light: SPECTROLINE, ENF-280C/FBE, 8 W).

Fabrication of warm WLEDs

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UV-LED chips (LUMEX-SSLLXTO46UV1C) with the peak emission wavelength centered at 400 nm were used for the fabrication of warm WLEDs. A certain amount solid ultra-BWCQDs were mixed with silicone directly and the obtained phosphor-silicone mixture was coated on the surface of the UV-LED chips to produce warm WLEDs. The photoelectric properties of the fabricated devices were measured by an integrating sphere spectroradiometer system (LHS-1000, Everfine). Fabricated devices were measured by an integrating sphere spectroradiometer system (LHS-1000, Everfine).

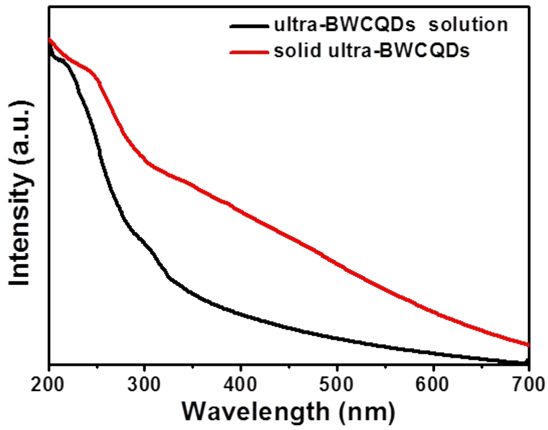

Figure S1. The absorption spectra of ultra-BWCQDs aqueous solution and solid ultra-BWCQDs

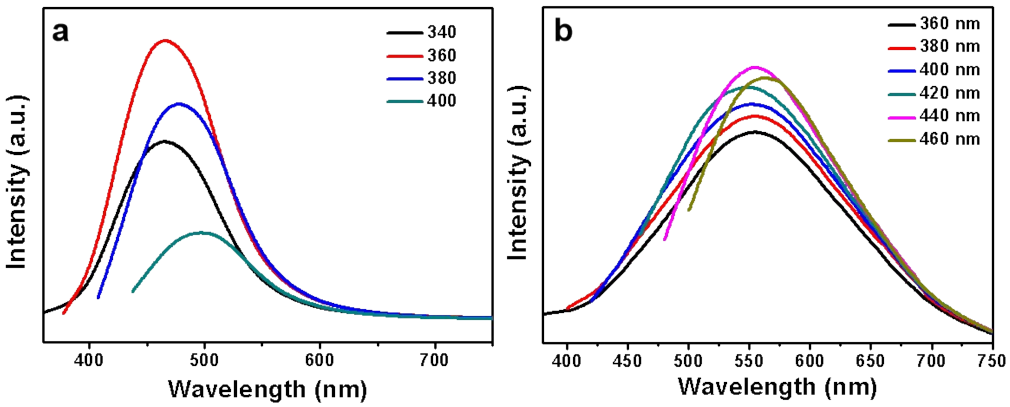

Figure S2. PL spectra of aqueous (a) and solid ultra-BWCQD (b) excited by different wavelength .

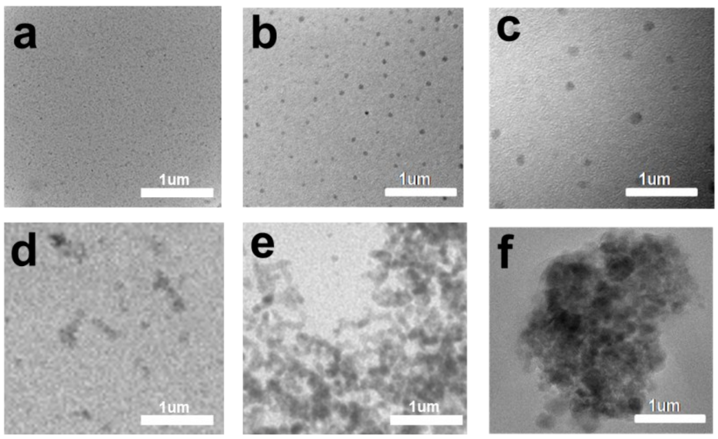

Figure S3. The TEM images of the aggregation of ultra-BWCQDs from different concentrations of 0.3 mg/ml (a), 0.6 mg/ml (b), 0.9 mg/ml (c), 1.2 mg/ml (d), 1.5 mg/ml (e), and 1.8 mg/ml (f), respectively.

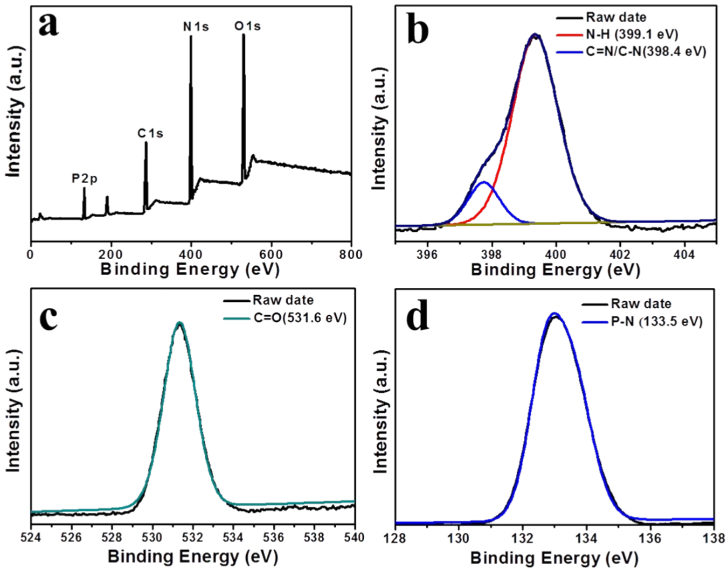

Figure S4. XPS survey (a) , deconvoluted high-resolution XPS N 1s (b), O1s (c) and P2P (d) spectra of solid ultra-BWCQDs.

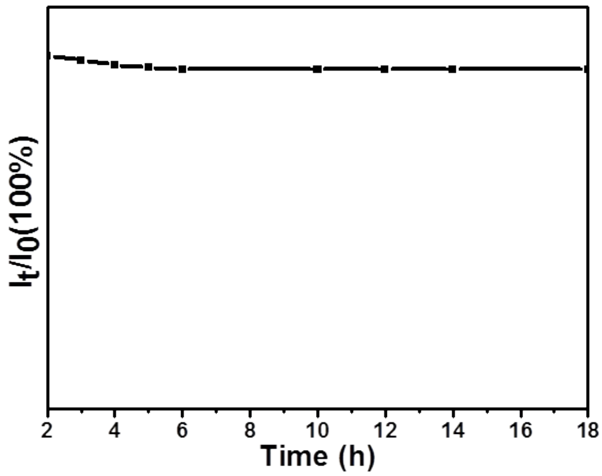

Figure S5. The photostability of solid ultra-BWCQDs under continuous radiation with a UV lamp for 18 h.

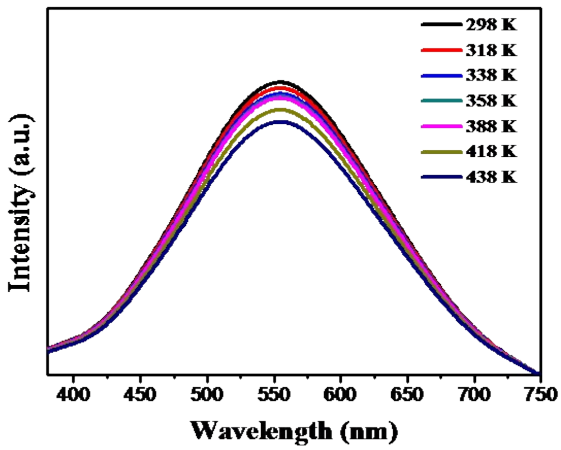

Figure S6. Temperature dependent fluorescence spectra of solid ultra-BWCQDs

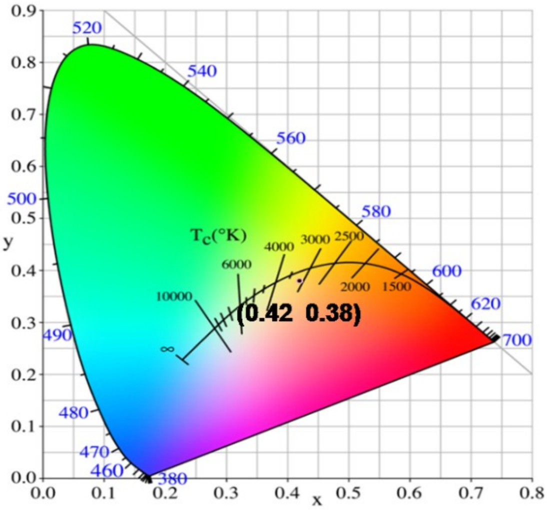

Figure S7. CIE color coordinate of the warm WLED lamp

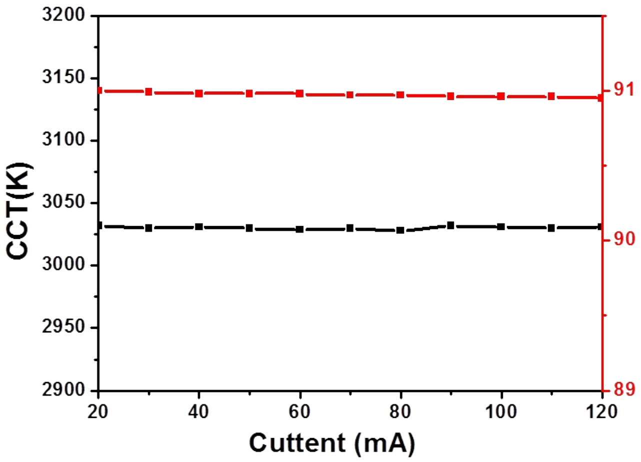

Figure S8. The CCT and CRI values of the warm WLED lamp under different drive currents.

Table S1. Comparison of CRI of single-component warm WLEDs based on semiconductor quantum dots and rare-earth phosphors and solid ultra-BWCQDs

Luminescent materials	CIE(X,Y)	CCT(K)	CRI	References
$BaMg_2(PO_4)_2$:3 %Eu^{2+}, 3 %Mn^{2+}, 3 %Tb^{3+}	(0.35, 0.30)	4464	82.8	21
Mn doped Zn-In-S QD	(0.38 0.27)	2716	66	22
$Ba_{0.93}Eu_{0.07}Al_2O_4$		3910	85	23
solid ultra-BWCQDs	(0.42 0.38)	2932	91	this work

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