Supporting Information

Room-temperature phosphorescent sodium carboxymethyl cellul-ose composites with ZnO Quantum Dots

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Experimental Section

1. Materials

Zinc acetate dihydrate (AR), sodium carboxymethyl cellulose (CMC) (20 g/L, viscosity: 800~1200 mPa·s at 25 °C), (3-aminopropyl)triethoxysilane (APTES) (AR), and anhydrous ethanol (AR) were purchased from Sinopharm Chemical Reagent Co., Ltd. Lithium hydroxide monohydrate (AR) was supplied by Shanghai Aladdin Biochemical Technology Co., Ltd. Deionized (DI) water (18.2 MΩ·cm) was used in all experiments, and all reagents were used as received without further purification.

2. Preparation of ZnO QDs modified by APTES

ZnO quantum dots (ZnO QDs) were synthesized via the sol-gel method. The detailed procedure was as follows. 1.0 g Zinc acetate dihydrate ($Zn(CH_3COO)_2 \cdot 2H_2O$) was dissolved in 50 mL anhydrous ethanol with continuous stirring at 78 °C until a transparent solution was formed. Afterward, 0.4 g lithium hydroxide monohydrate ($LiOH \cdot H_2O$) was ultrasonically dissolved in 25 mL anhydrous ethanol to afford an alkaline solution. Under an ice-water bath, the alkaline ethanol solution was slowly added dropwise into the zinc acetate solution. The mixture was allowed to react for 1 h. Subsequently, a mixture of 500 μL APTES and 1 mL H_2O was introduced into the

reacted mixture, leading to the formation of a white precipitate. The solid product was collected by centrifugation (8000 rpm, 7 min), washed three times with ethanol, and finally vacuum-dried at 60 °C for overnight to obtain blue-fluorescent ZnO QDs, denoted as B-ZnO QDs.

3. Preparation of ZnO QDs/CMC composite films

First, given amounts of B-ZnO QDs were ultrasonically dispersed in varied volumes of deionized water to obtain aqueous suspensions. Subsequently, 1.0 g CMC was added to each suspension with rigorous stirring, and the mixtures were continuously stirred for overnight to obtain homogeneous B-ZnO QDs/CMC (Z-C) blends. The detailed formulations are summarized in Table S1. Finally, the Z-C blends were casted onto glass dishes, allowed to solidify at room temperature for 48 h, and then transferred to a vacuum oven and dried at 60 °C for 10 h to produce Z-C composite films.

4. Characterization

Morphology of the as-obtained B-ZnO QDs was characterized using a Talos F200X G2 transmission electron microscope (TEM, FEI, USA) operated at 200 kV. Powder X-ray diffraction (XRD) patterns were recorded on an Empyrean X-ray diffractometer (Malvern Panalytical, the Netherlands) using Cu Kα radiation. Fourier-transform infrared (FTIR) spectra of B-ZnO QDs, CMC, and Z-C composites were collected at room temperature using a Bruker ALPHA II spectrometer in attenuated total reflection mode over the spectral range of 4000–400 cm^{-1}. Surface compositions of B-ZnO QDs were analyzed by X-ray photoelectron spectroscopy (XPS) using a Thermo Scientific ESCALAB Xi+ spectrometer (USA). UV-Vis absorption spectra of the aqueous dispersion of B-ZnO QDs were acquired using a Model A spectrophotometer (Aoyi Instrument Co., Ltd., Shanghai). Room-temperature fluorescence and phosphorescence spectra of the samples were recorded using a Hitachi F-4700 fluorescence spectrophotometer equipped with a xenon lamp excitation source. Photoluminescence decay curves and absolute quantum yield (PLQY) of B-ZnO QDs were measured using the FLS-1000 spectrophotometer with an integrating sphere (Edinburgh, UK). Ultraviolet (UV) protection performance of the CMC and Z-C films

was evaluated by measuring their UV transmittance and ultraviolet protection factor (UPF) using an RF-902A fabric UV protection tester (Shanghai Ruifang Instrument Co., Ltd., China).

Table S1. The detailed recipe of the Z-C mixture

Sample	CMC (g)	ZnO QDs (g)	Water (g)	Weight percent of ZnO QDs (%)
Z-C-0.5	1.0	0.15	28.85	0.5
Z-C-1	1.0	0.30	28.70	1.0
Z-C-2	1.0	0.60	28.40	2.0
Z-C-3	1.0	0.90	28.10	3.0

Table S2. Enhancement of UV Shielding Properties by incorporation of ZnO QDs into CMC Matrix.

Sample	UPF	UVA transmittance (%)	UVB transmittance (%)	Solid content of B-ZnO QDs (%)
CMC	1.66	70.85	55.12	0
Z-C-0.5	60.46	20.51	0.13	13.04%
Z-C-1	65.07	18.97	0.12	23.08%
Z-C-2	176.85	7.96	0.04	37.50%
Z-C-3	482.21	3.45	0.01	47.37%

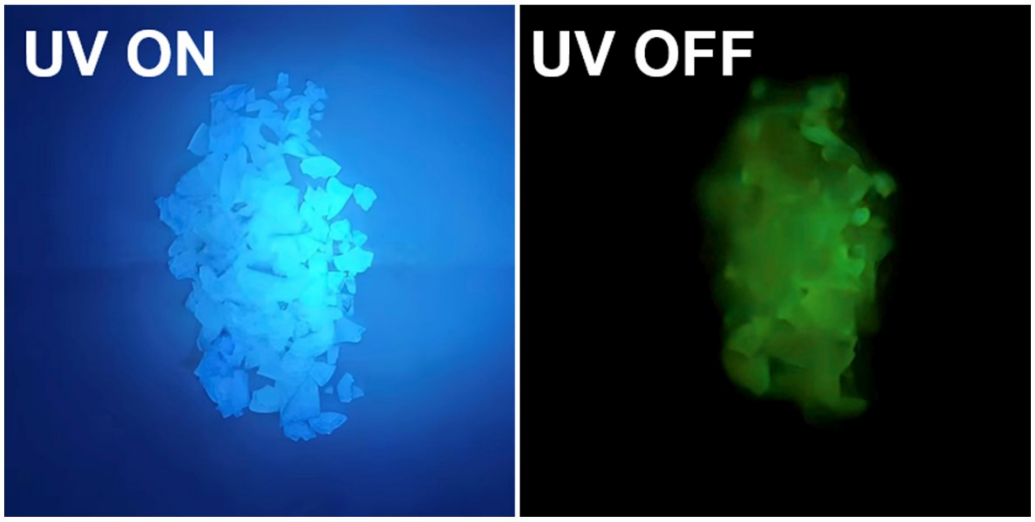

Fig. S1. Photographs of the B-ZnO QDs under 365 nm UV lamp on and off.

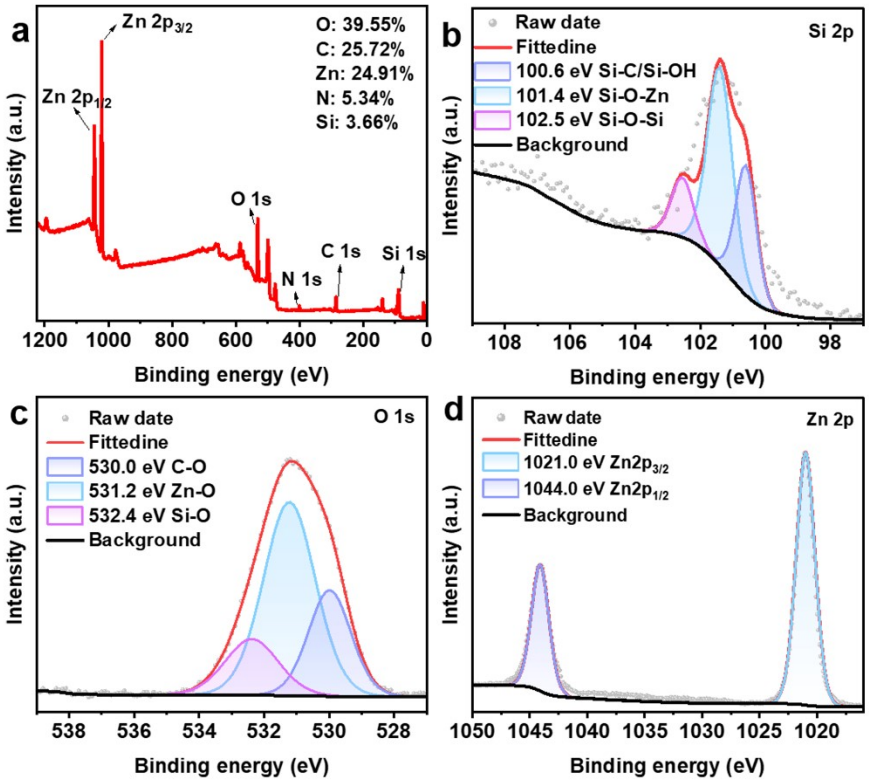

Fig. S2. a) XPS survey spectrum of B-ZnO QDs. High-resolution XPS spectra and fitting results of the B-ZnO QDs: b) Si 2p, c) O1s, and d) Zn 2p.

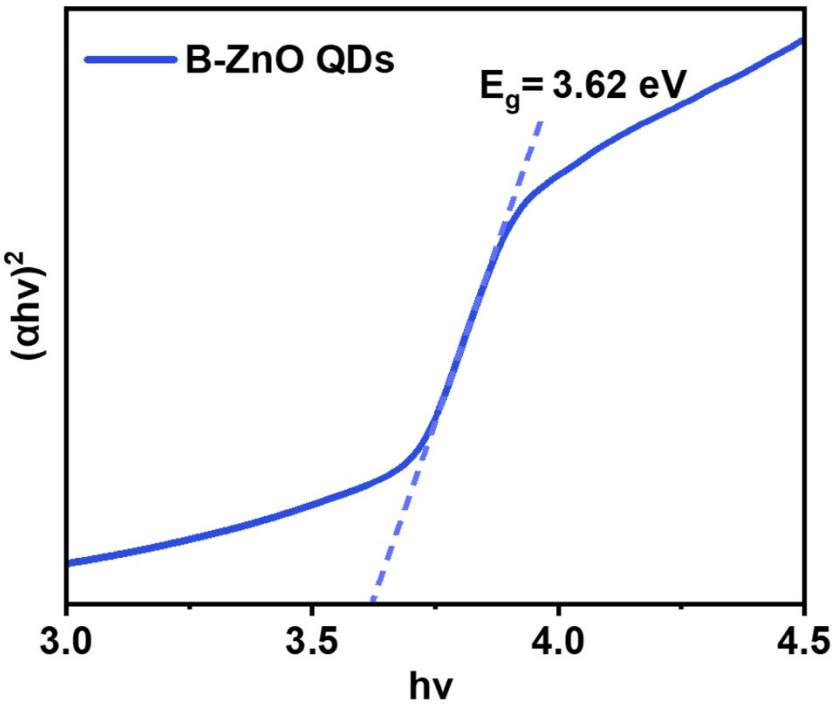

Fig. S3. B-ZnO QDs absorption band gap diagram.

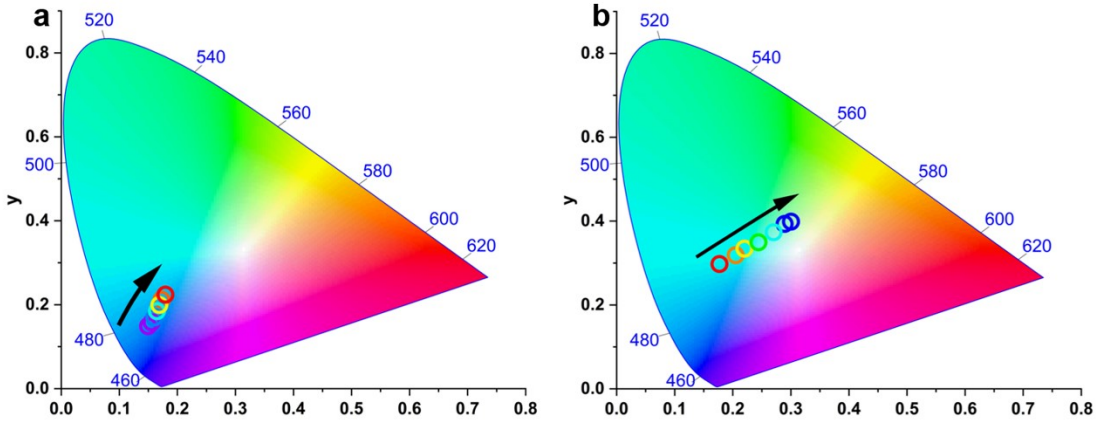

Fig. S4. The color gamut diagram of B-ZnO QDs when the emission wavelength increases with an increase of excitation wavelength: a) PL and b) RTP.

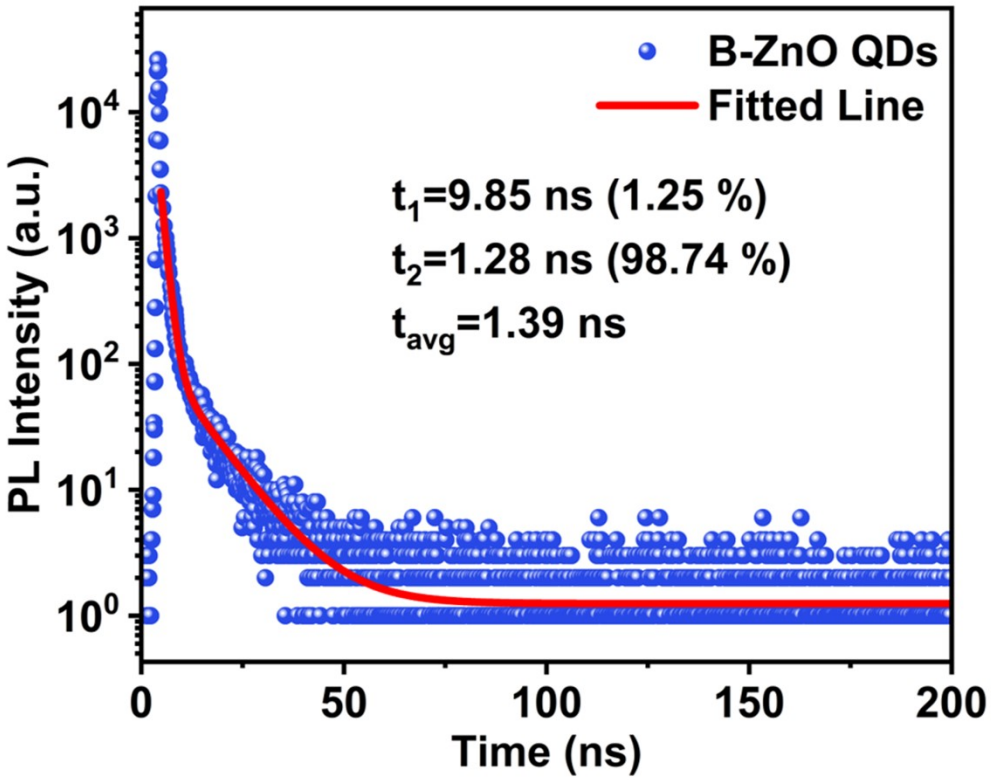

Fig. S5. PL decay spectrum of the solid-state B-ZnO QDs, recorded at emission wavelengths of 450 nm under excitation at 330 nm.

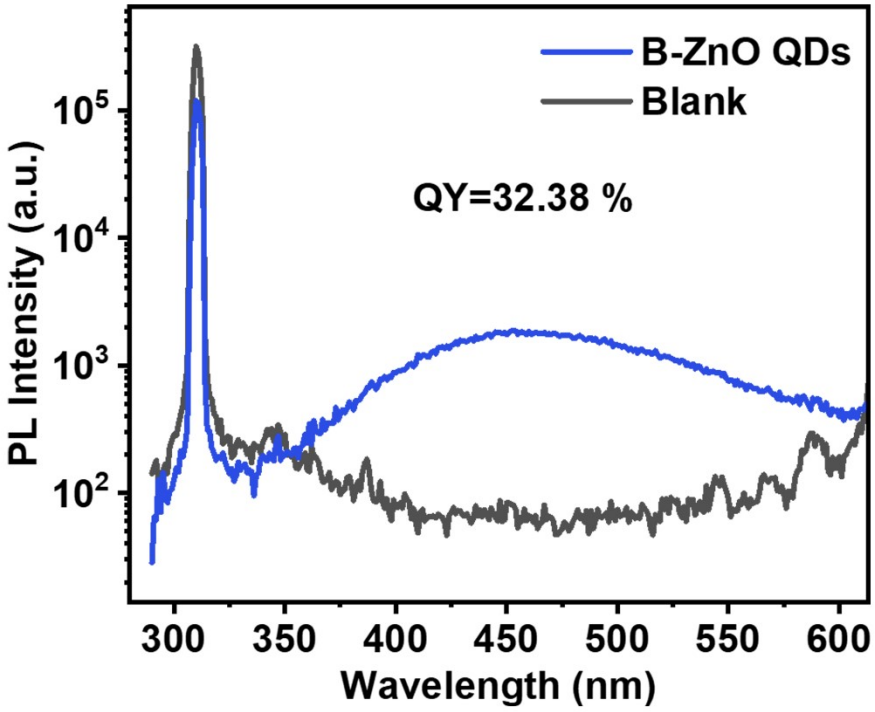

Fig. S6. Absolute quantum yield of the B-ZnO QDs.

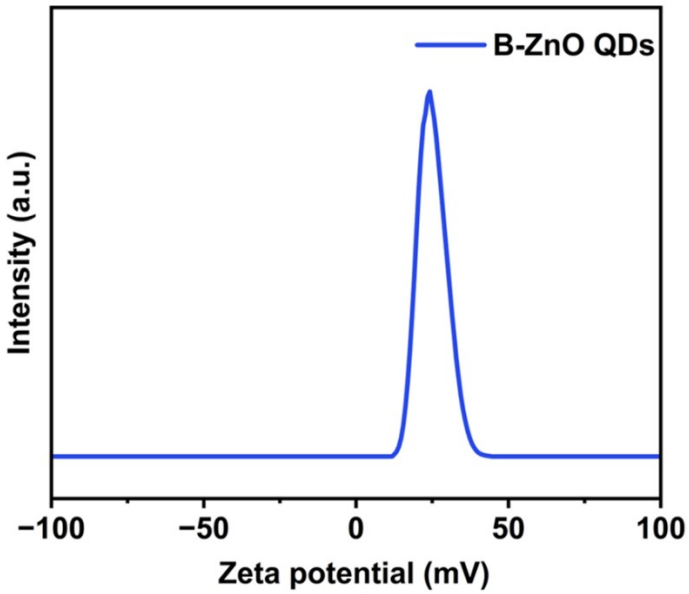

Fig. S7. Surface Zeta potential distribution profile of B-ZnO QDs in aqueous dispersion.

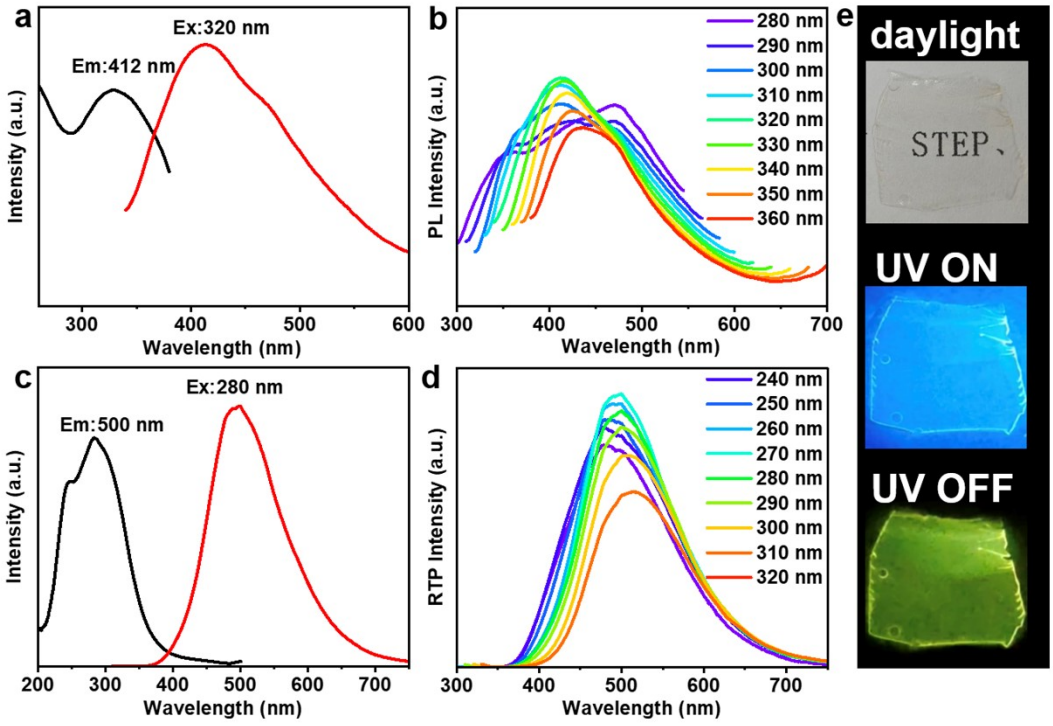

Fig. S8. a) PL excitation and emission spectra of the pure CMC film, b) PL spectra of the CMC film under varied excitation wavelengths ranging from 280 nm to 370 nm. c) RTP excitation and emission spectra of the pure CMC film, (d) RTP spectra of the pure CMC film under varied excitation wavelengths ranging from 230 nm to 330 nm, e) Photographs of the CMC film under daylight and with a 365 nm UV lamp on and off.

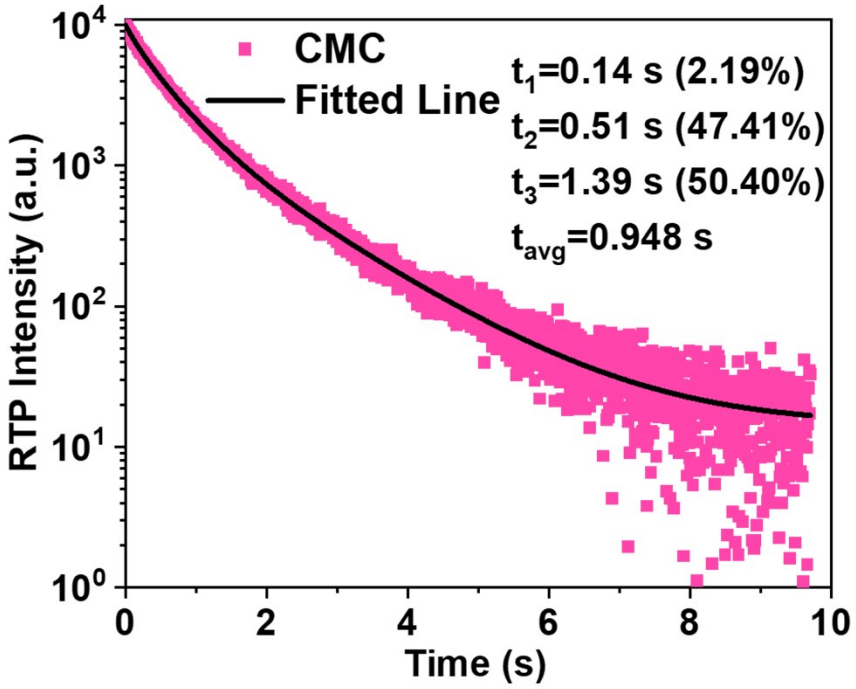

Fig. S9. RTP decay spectrum of the CMC film, recorded at emission wavelength of 500 nm under excitation wavelength of 280 nm.

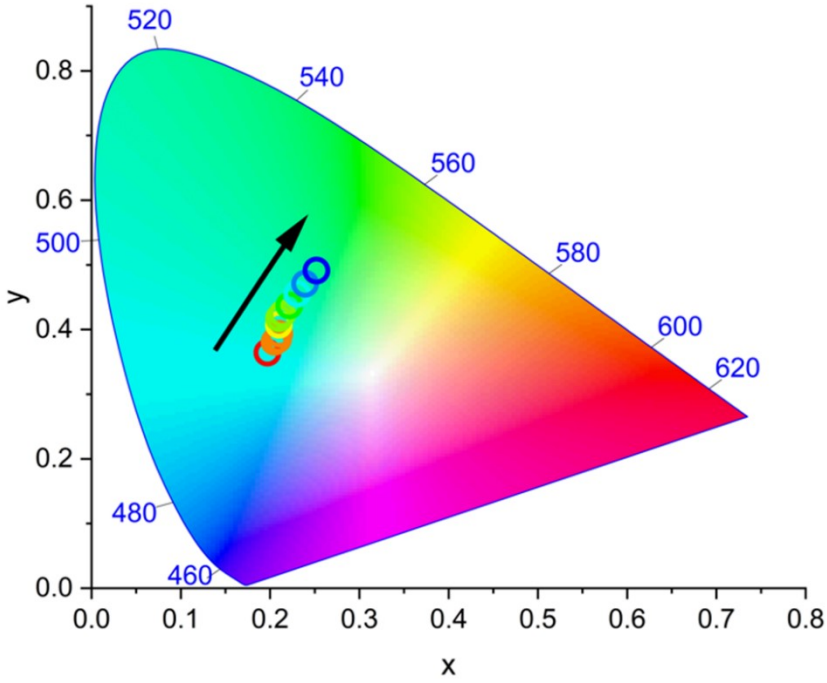

Fig. S10. The RTP color gamut map of the CMC film with the increased excitation wavelength.

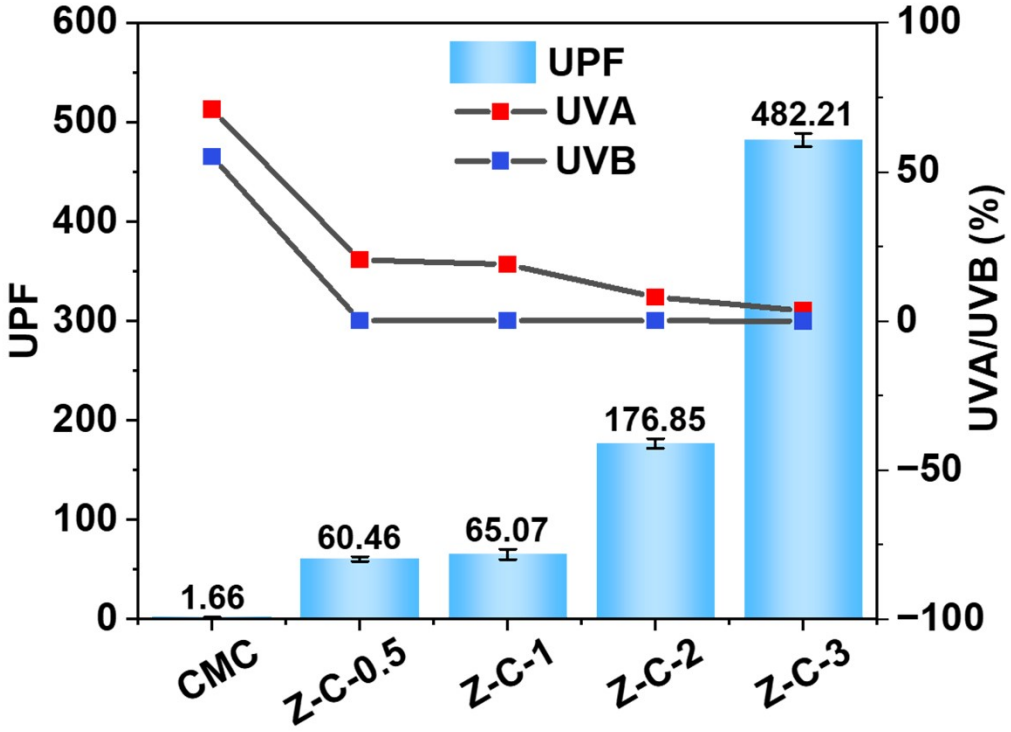

Fig. S11. Z-C films containing varied loading of B-ZnO QDs: Ultraviolet protection coefficient (UPF), UVA and UVB values. UV: ultraviolet.