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Modulating Multi-color Room Temperature Phosphorescence Emission for Carbon Dots Composites with Ultralong Lifetime

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Experimental

Materials

Adipic acid and boric acid were purchased from Aladdin Reagent Corporation (Shanghai, China). All of the reagents were used directly without further purification. The deionized water used throughout all the experiments was purified through Water Purifier Nanopure water system (18.25 M.cm).

The Synthesis of BCDs

Typically, 3 g of boric acid (BA), 0.05 g of adipic acid were dissolved in 40 mL of deionized water in a 100 mL beaker. Meanwhile, the beaker was covered with aluminum foil to keep the water evaporating slowly. And then, the beaker heated to 180°C for 5 h in a draught drying cabinet. After cooled down to room temperature naturally, finally, **BCDs-50 180** were obtained by grinding.

The Synthesis of BCDs-xxx xxx

The synthesis BCDs-xxx xxx(the superscript represents the precursor mass, the subscript is the reaction temperature) process in accord with preparation of BCDs, including **BCDs-100 180**, **BCDs-200 180**, **BCDs-500 180**, **BCDs-50 200**, **BCDs-100 200**, **BCDs-200 200**, **BCDs-500 200**, **BCDs-50 220**, **BCDs-100 220**, **BCDs-200 220** and **BCDs-500 220**. Finally, these carbon dots are collectively referred to as **BCDs**.

In vitro cellular imaging

HuH-7 cells were plated with 2×10^5 cells/dishes in a 20 mm glass bottom cell culture dish and cultured in 2 ml Dulbecco's modified Eagle's medium (DMEM) mixed with 10% of fetal bovine serum (FBS) and 1% penicillin-streptomycin for 12 h (37 °C, 5% CO₂). Next, the cells were washed with phosphate buffered saline (PBS) buffer, and were incubated with 2 mg/mL BCDs-50 200 in 2 ml DMEM medium for 6 h. After that, the excess BCDs-50 200 were removed by washing three times with PBS buffer.

Characterization

The transmission electron microscopy (TEM) was recorded on FEI Tecnai G2 F20 S-TWIN system operating at 200 kV (America). XRD patterns were obtained with a Smart Lab 9 kW using Cu Ka radiation (Japan). Fourier transform infrared (FT-IR) spectrum of BCDs were recorded on a Bruker Vertex-22 spectrometer from 4000 to 500 cm⁻¹. X-Ray photoelectron spectroscopy (XPS) were obtained on a Thermo Fisher (USA) ESCALAB 250Xi Multitechnique Surface Analysis. The UV-visible absorption absorbance

spectra of BCDs were recorded by using a Cary 5000 (America). Fluorescence spectrophotometry F7100 (Japan) was applied to record the fluorescence and phosphorescence spectra of BCDs. Transient Fluorescence Spectrometry FLS1000 was recorded on phosphorescence lifetime of BCDs. Quantum Efficiency Measurement System C9920-02G was recorded on photoluminescence quantum yield. The cells images were obtained using a confocal laser scanning microscope (Leica TCS SP8, Germany) at 405 nm excitation. The digital photos were recorded by the iPhone XR.

Supplementary Figures

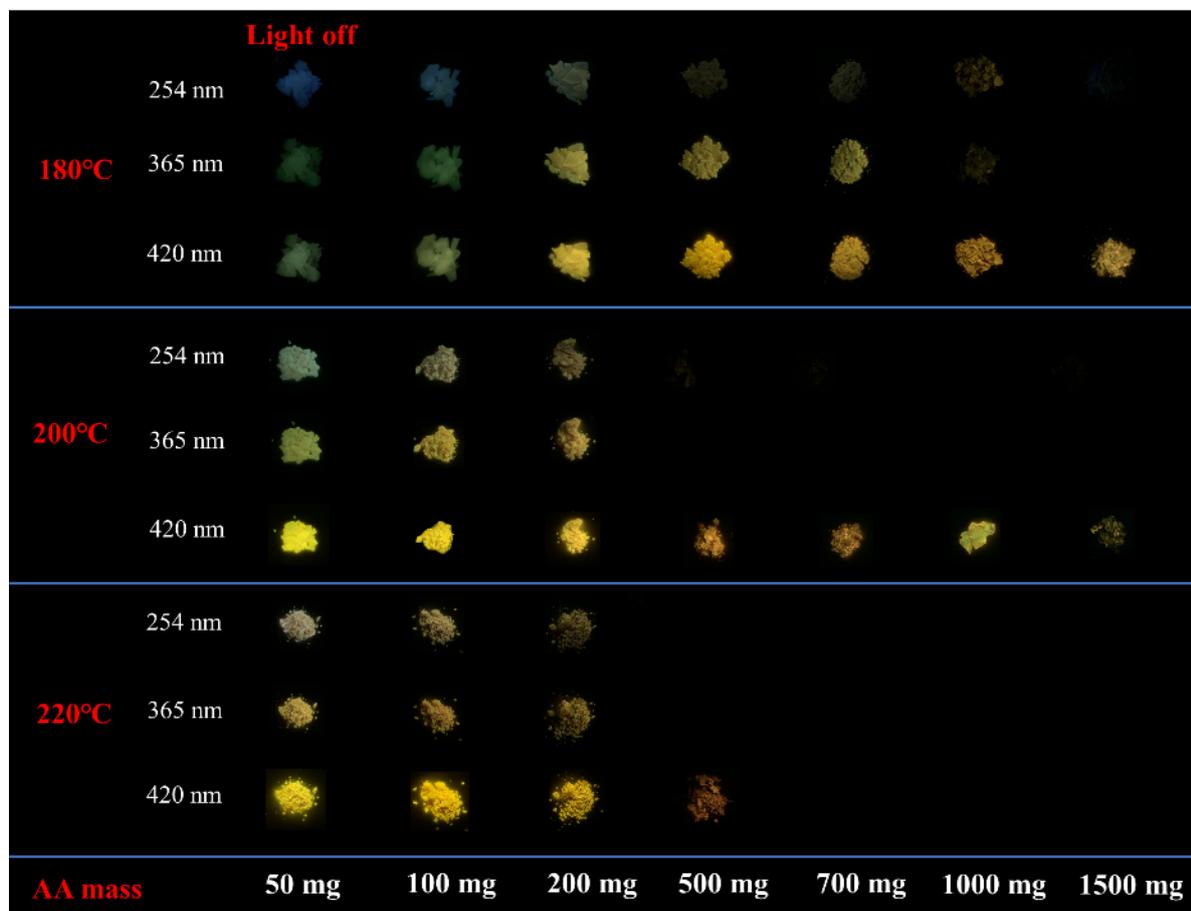


Figure S1. The phosphorescence pictures of BCDs under 254 nm, 365 nm and 420 nm excitation.

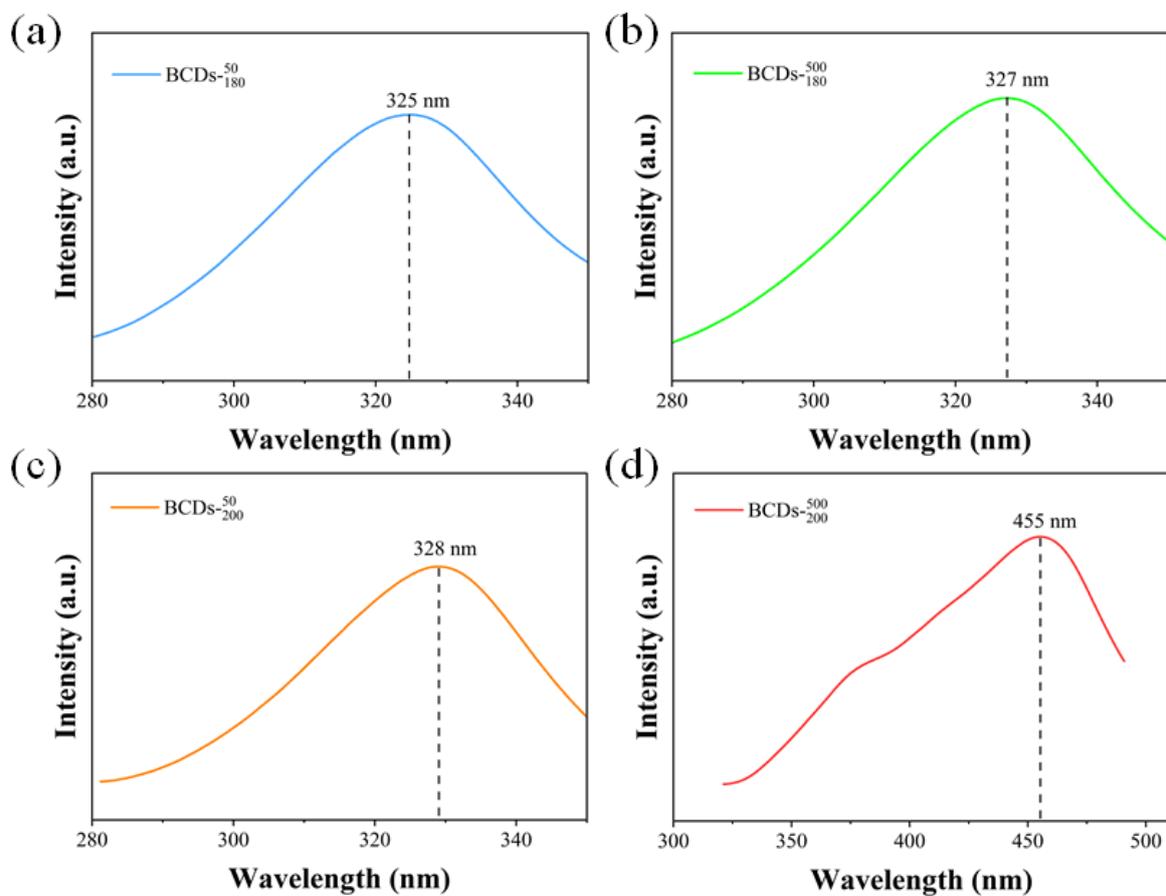


Figure S2. The fluorescence excitation spectra of (a) BCDs-50 180, (b) BCDs-500 180, (c) BCDs-50 200 and (d) BCDs-500 200.

The fluorescence excitation spectra of (a) BCDs-50 180, (b) BCDs-500 180, (c) BCDs-50 200 and (d) BCDs-500 200 were obtained by fixing the emissions wavelengths at 363 nm, 363 nm, 358 nm and 505 nm, respectively.

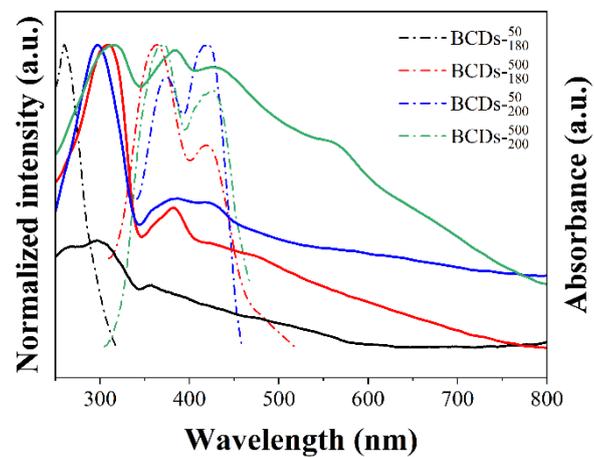


Figure S3. The phosphorescence excitation spectra (dot dash line) and UV-vis optical absorption spectra (full line) of BCDs using excitation wavelengths of 435 nm, 523 nm, 539 nm, and 526 nm, respectively.

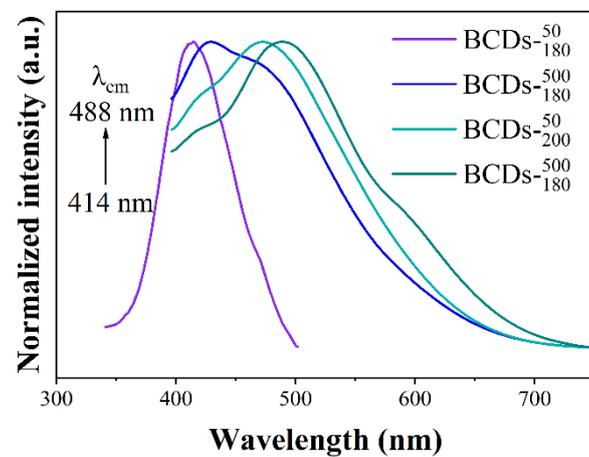


Figure S4. The FL spectra of BCDs under excitation wavelengths of 260 nm, 380 nm, 380 nm, and 380 nm.

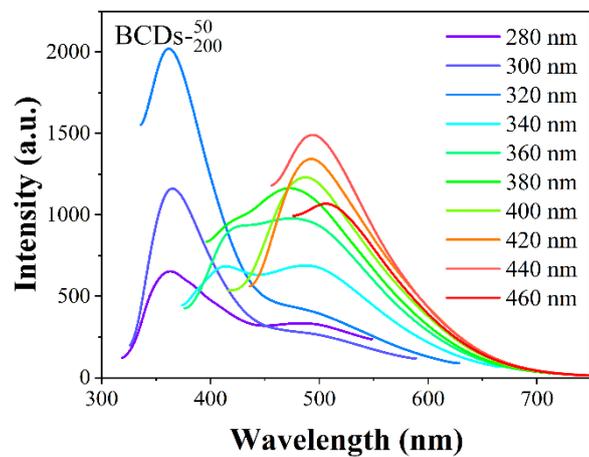


Figure S5. The FL emission spectra of BCDs-50 200 excited from 280 to 460 nm.

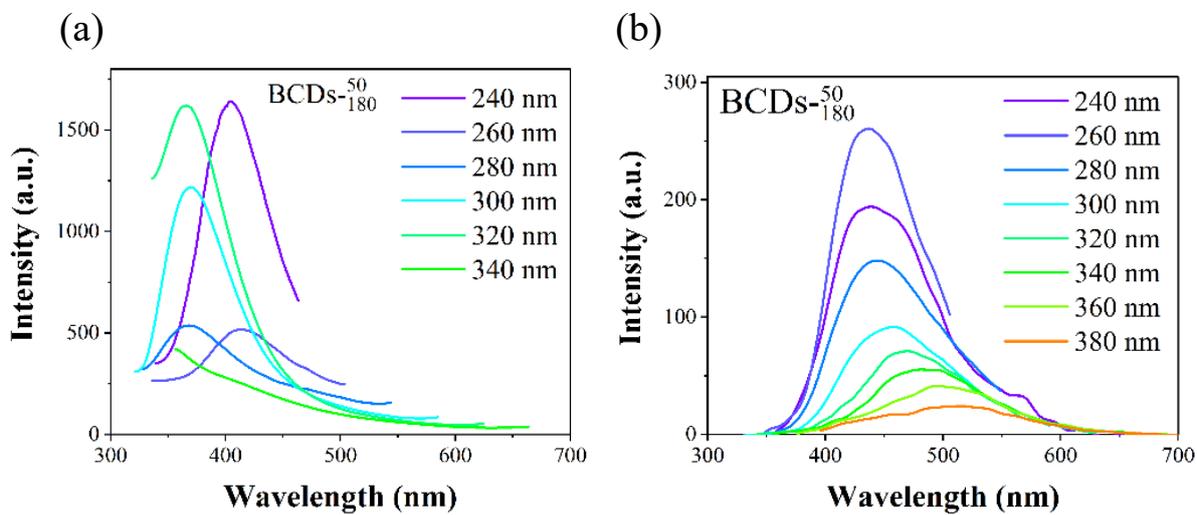


Figure S6. (a) The FL emission spectra of BCDs-50 180 excited from 240 to 340 nm. (b) The phosphorescence emission spectra of BCDs-50 180 excited from 240 to 380 nm.

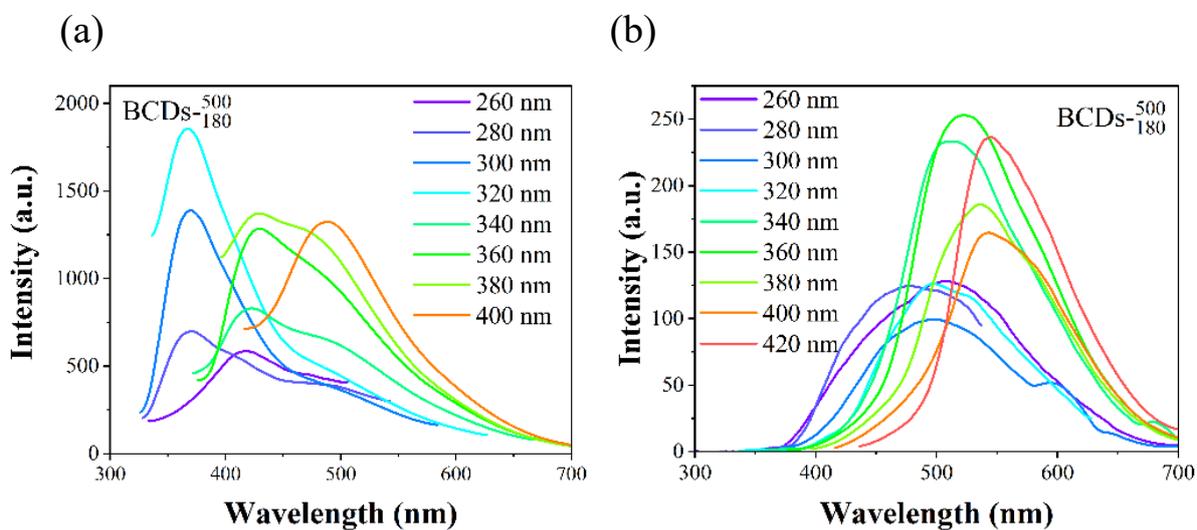


Figure S7. (a) The FL emission spectra of BCDs-500 180 excited from 260 to 400 nm. (b) The phosphorescence emission spectra of BCDs-500 180 excited from 260 to 420 nm.

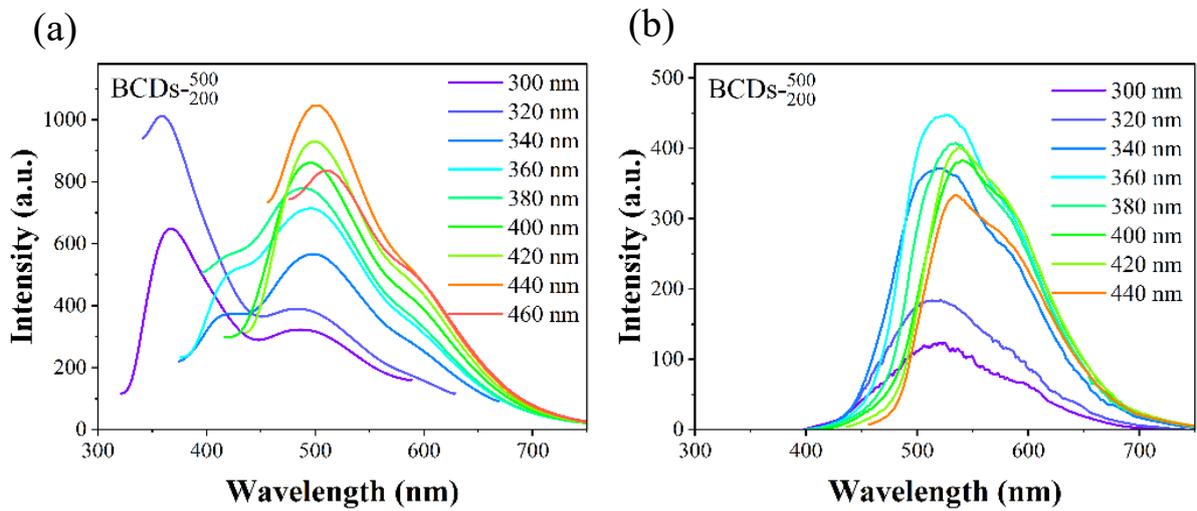


Figure S8. (a) The FL emission spectra of BCDs-500 200 excited from 300 to 460 nm. (b) The phosphorescence emission spectra of BCDs-500 200 excited from 300 to 440 nm.

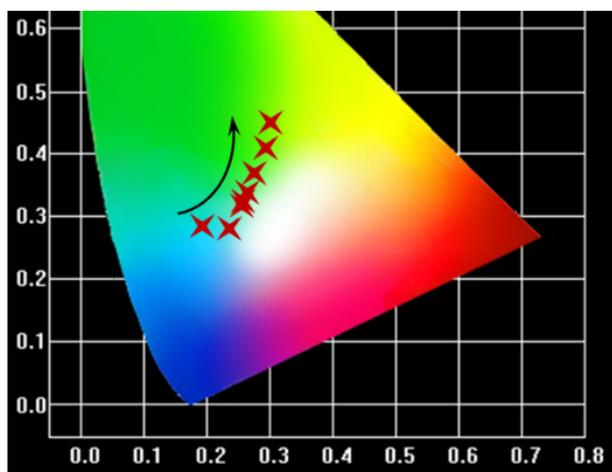


Figure S9. CIE coordinates of the FL properties of BCDs-500 200.

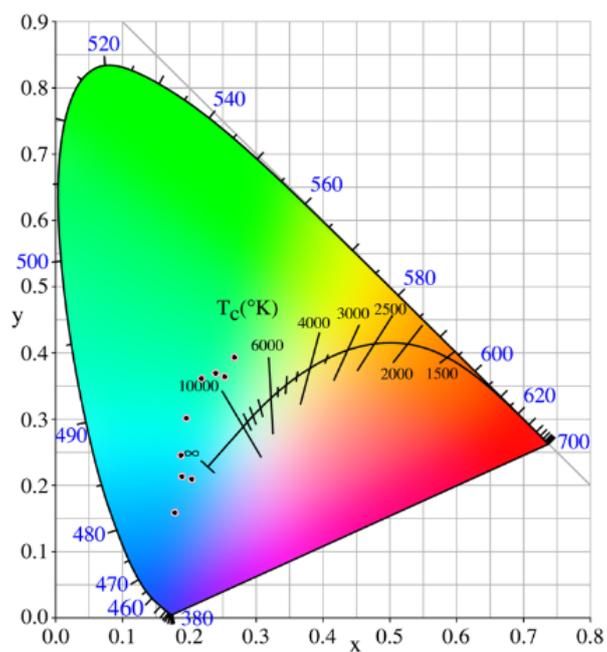


Figure S10. CIE coordinates of the phosphorescence properties of BCDs-50 180.

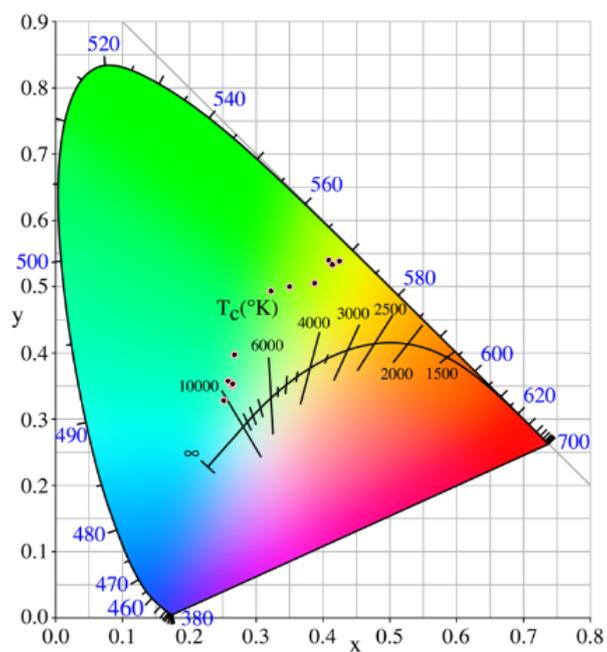


Figure S11. CIE coordinates of the phosphorescence properties of BCDs-500 180.

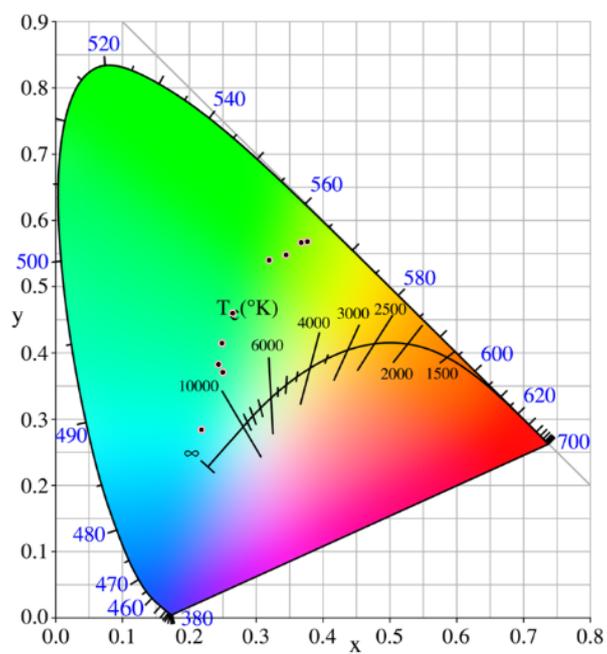


Figure S12. CIE coordinates of the phosphorescence properties of BCDs-50 200.

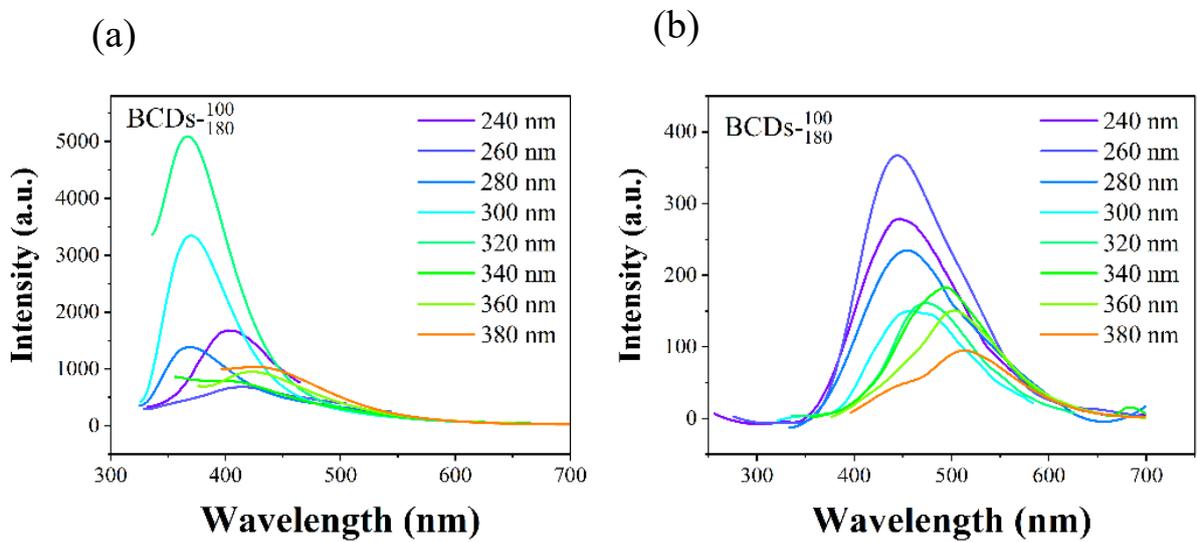


Figure S13. (a) The FL emission spectra of BCDs-100 180 excited from 240 to 380 nm. (b) The phosphorescence emission spectra of BCDs-100 180 excited from 240 to 380 nm.

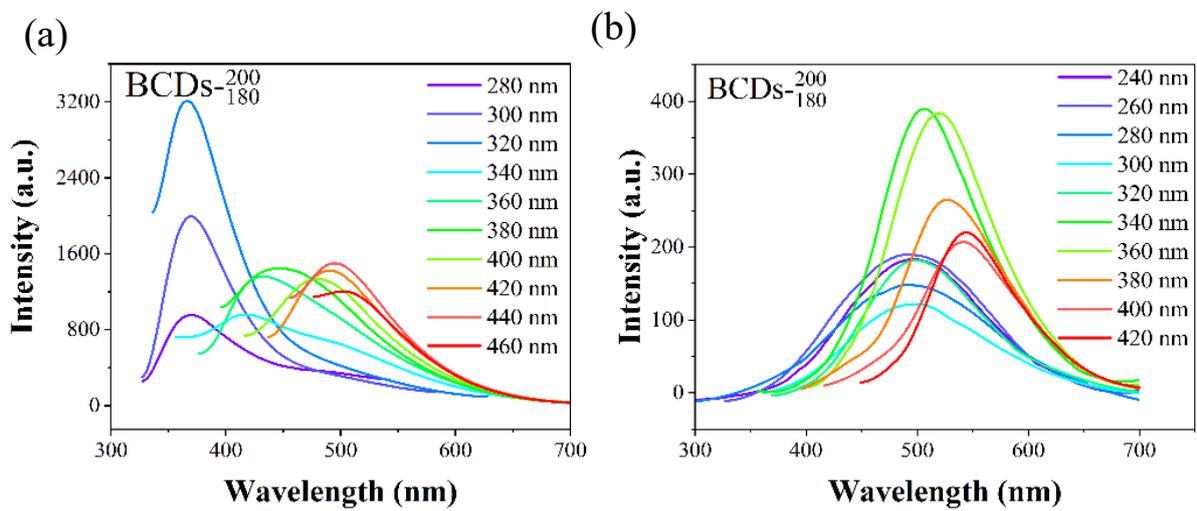


Figure S14. The FL emission spectra of BCDs-200 180 excited from 280 to 460 nm. (b) The phosphorescence emission spectra of BCDs-200 180 excited from 240 to 420 nm.

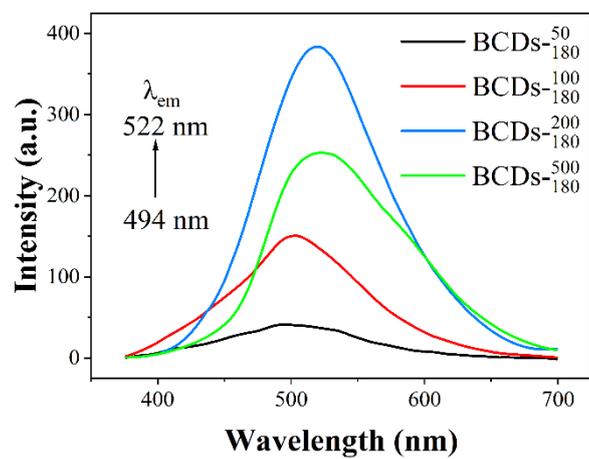


Figure S15. The phosphorescence emission spectra of BCDs-50 180, BCDs-100 180, BCDs-200 180, BCDs-500 180 under 360 nm excitation.

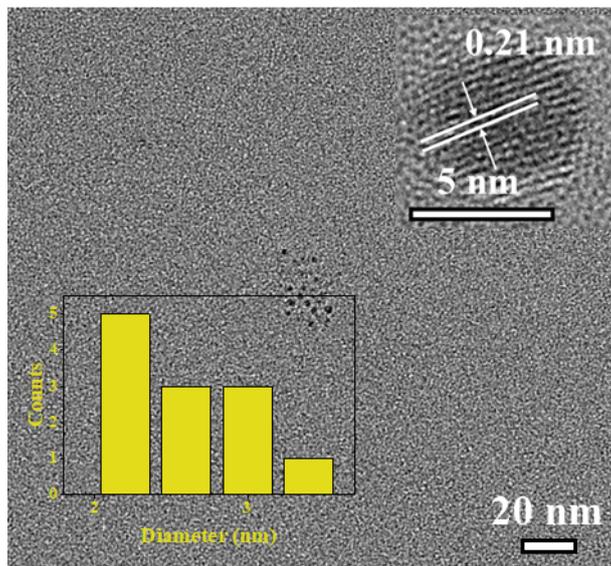


Figure S16. TEM images of BCDs-50 200 (inset: size distribution and HRTEM images of BCDs-50 200).

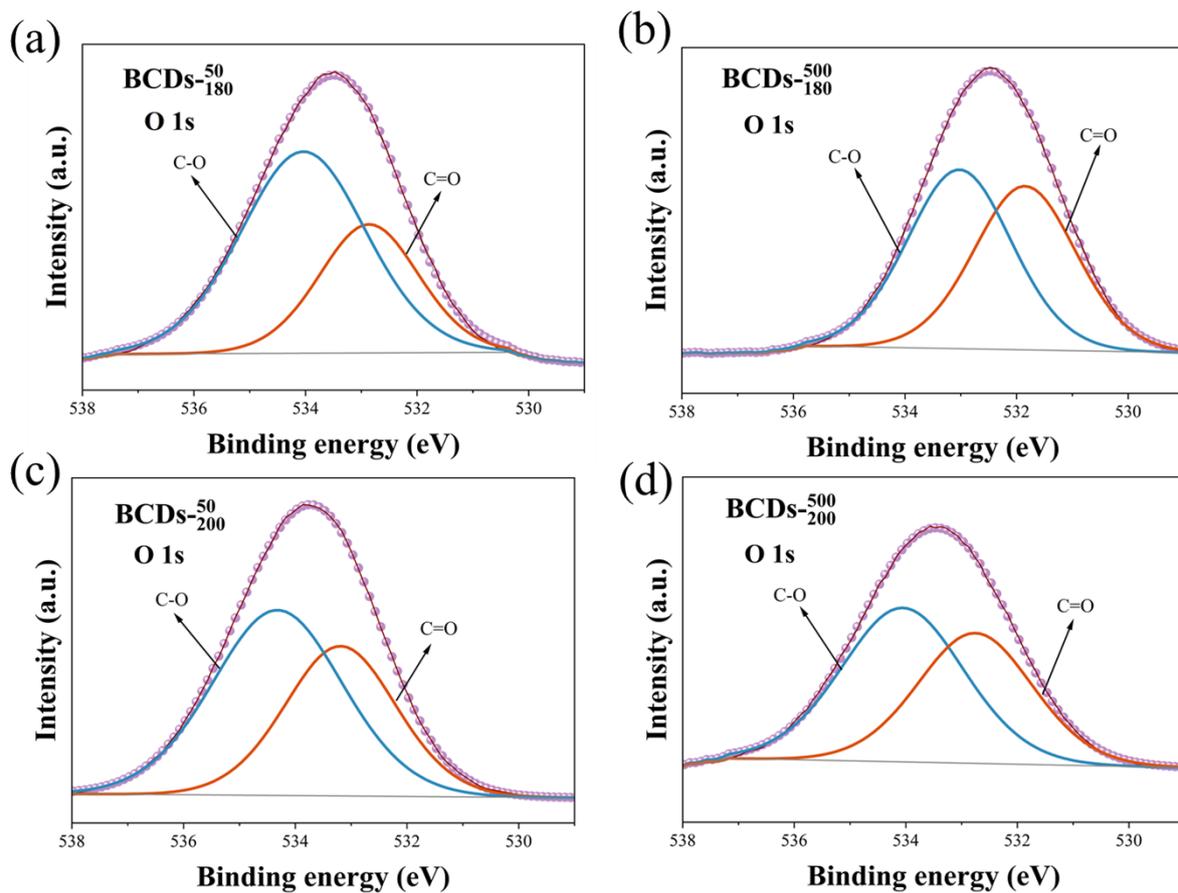


Figure S17. The HR XPS O 1s (a) BCDs-50 180, (b) BCDs-500 180, (c) BCDs-50 200 and (d) BCDs-500 200.

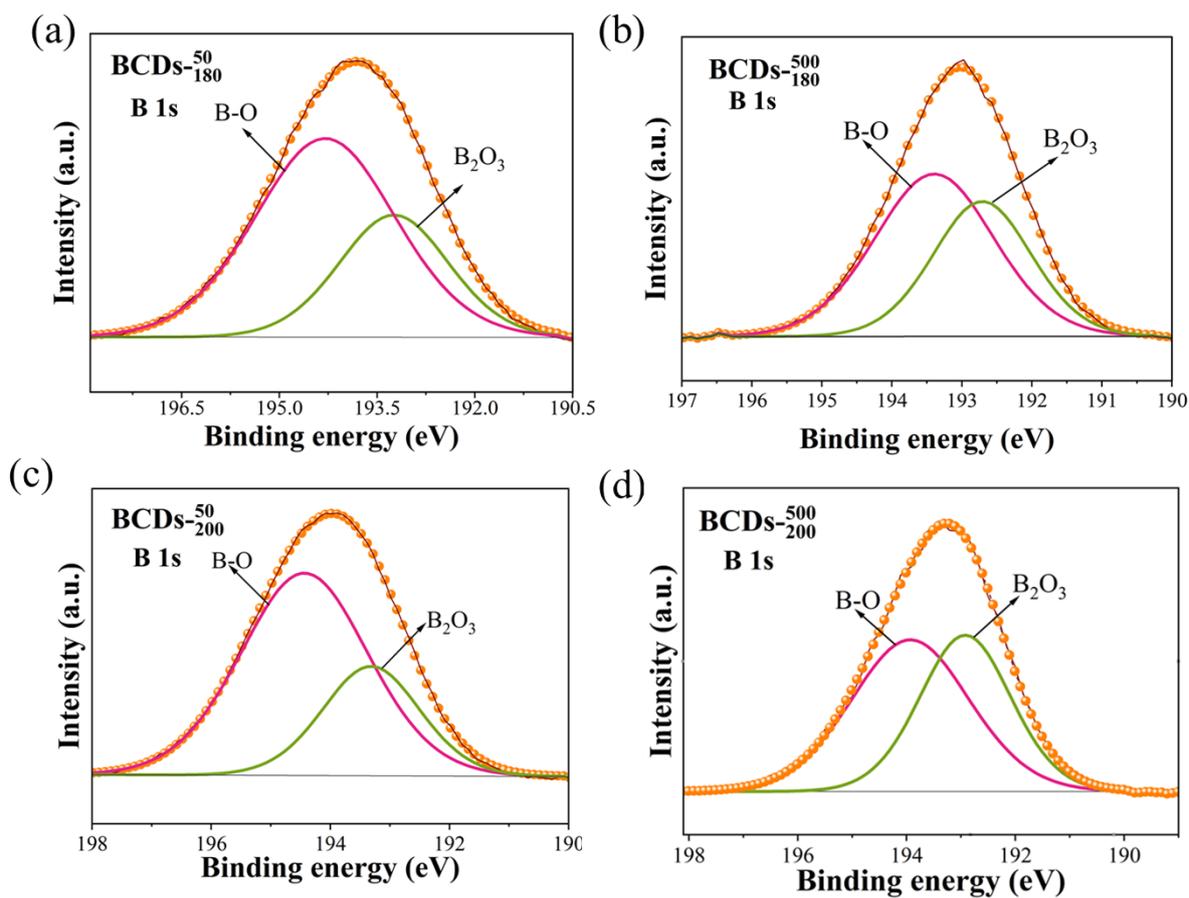


Figure S18. The HR XPS B 1s (a) BCDs-50 180, (b) BCDs-500 180, (c) BCDs-50 200 and (d) BCDs-500 200.

Table S1. Photophysical characteristics of BCDs.

	λ_{em}	A ₁	τ_1	A ₂	τ_2	A ₃	τ_3	τ_{ave}
	(nm)	(%)	(ms)	(%)	(ms)	(%)	(ms)	(ms)
BCDs-50 180	435	6.97	20.22	27.90	196.25	65.13	1174.81	821.32
BCDs-500 180	523	7.99	19.28	32.38	267.60	59.63	1129.72	761.84
BCDs-50 200	539	3.22	26.98	31.63	387.50	65.15	1194.17	901.44
BCDs-500 200	526	3.38	16.31	25.00	248.00	71.63	901.07	707.99

Table S2. XPS data analyses of C1s, B1s and O1s spectra of BCDs.

	Chemical bond (%)	3CDs-50 180	CDs-500 180	3CDs-50 200	CDs-500 200
C 1s	C-O/C-O-B	46.7	46.04	56.1	50.1
	C-C/C=C	40.5	26.16	29.4	22.6
	C=O	12.8	27.8	14.5	27.3
B 1s	B-O	66.7	54.05	69.94	58.51
	B ₂ O ₃	33.3	45.95	30.05	41.49
O 1s	C-O	66.27	47.25	51.17	55.78
	C=O	33.73	51.75	40.83	44.22