Electronic Supplementary Material (ESI) for Nanoscale Advances.
This journal is © The Royal Society of Chemistry 2021

Supplementary information

Highly Stable and Bright Blue Light-Emitting Diodes Based on Carbon Dots with Chemically Inert Surface

Tianyang Zhang,[a] Xiao Wang,[a] Zhenyu Wu,[a] Tianyu Yang,[a] Han Zhao,[a] Jiawei Wang,[a] Hui Huang,[a] Yang Liu,[*,a] Zhenhui Kang,[*,a,b]

[a]Institute of Functional Nano and Soft Materials (FUNSOM), Jiangsu Key Laboratory for Carbon-based Functional Materials and Devices, Soochow University, Suzhou 215123, China.

[b]Macao Institute of Materials Science and Engineering, Macau University of Science and Technology, Taipa 999078, Macau SAR, China.

1. Supplementary Methods

1.1. Characterization

XRD pattern was collected by PIXcel3D X-ray diffractometer (Empyrean, Holland Panalytical) with Cu Kradiation (= 0.154178 nm). TEM and HRTEM images were acquired from FEI-Titan G^2 80–200 Chemi scanning transmission electron microscope, which has an accelerating voltage of 200 kV. Hyperion spectrophotometer (Bruker) was applied to make an analysis on the molecular structure and chemical composition by way of standard KBr pellet technique. UV/vis/NIR spectrophotometer (Lambda750, PerkinElmer) was used to obtain UV-vis spectra. Hitachi F-4600 fluorescence spectrophotometer was performed to obtain the PL spectra. A Princeton Instrument spectrometer which used a 325 nm fs laser (100 fs, 1 kHz) working as the excitation light source was used to measure temperature-dependent PL spectra and the temperature of the instrument was regulated by fluid nitrogen. The XPS spectra were measured by KRATOS Axis ultra-DLD X-ray photoelectron spectroscope with a monochromatic Al KX-ray source (hv= 1283.3 eV). The UPS spectra were recorded by an unfiltered He I (21.22 eV) gas discharge lamp and a total instrumental energy resolution of 100 MeV. The absolute PLQY was measured by the C9920-02G (HAMAMATSU) with an integrating sphere. The PL lifetime was obtained by a Hitachi F-4600 fluorescence spectrophotometer that applied a 370 nm pulsed laser working as the exciting light source.

1.2. Electroluminescence Characterizations of Carbon Dots Light-emitting Diodes

The process of the electroluminescence characterization of the devices was carried out in the air. The PL spectra were acquired by a Hitachi F-4600 fluorescence spectrophotometer that applied a 370 nm pulsed laser working as the exciting light source. The curves of the voltage versus current density and the luminance were measured by a photometer (Photo Research PR 655 spectrophotometer) which was adhered to the constant current source (Keithley 2400s Source Meter). The half lifetime (T_{50}) was recorded by a device lifetime decay test system made in Shanghai University. The EQE of the CDs-LEDs was calculated according to the following equation (1):

$$\eta_{EQE} = \eta_{int} \times \eta_{out} = \gamma \times \eta_r \times q \times \eta_{out} \quad (1)$$

Where the η_{int} is the internal quantum efficiency, η_{out} is the optical output coupling efficiency, γ is charge carrier balance ratio, η_r is the rate of emission exciton formation, and q is the radiation quantum yield.

2. Supplementary Figures

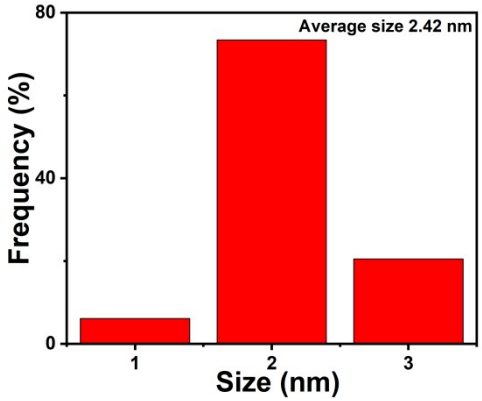

Figure S1. Corresponding size distribution of CDs in **Fig 1a.**

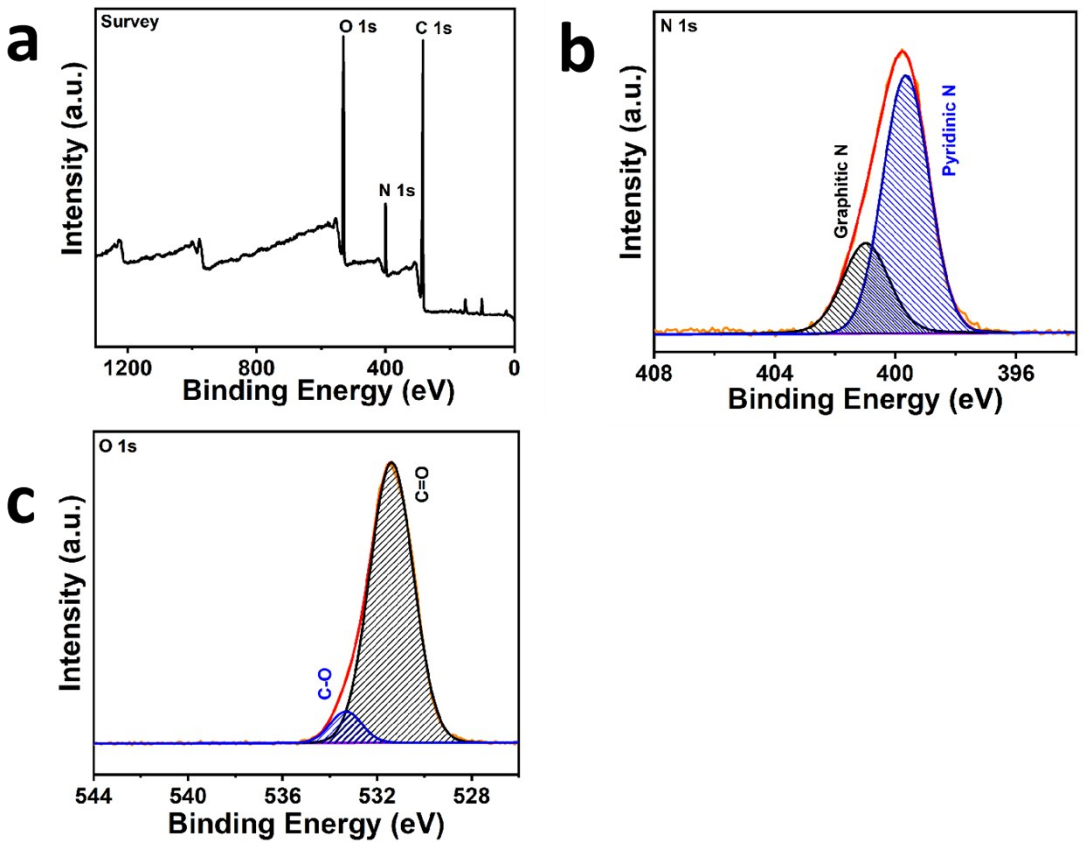

Figure S2. (a) XPS full survey spectrum, (b) High resolution N 1s XPS spectra, and (c) High resolution O 1s XPS spectra of CDs.

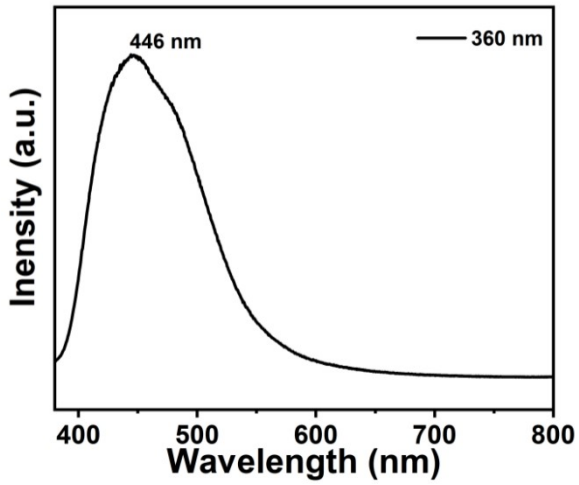

Figure S3. PL spectrum of CDs excited by Xenon light source of 360 nm.

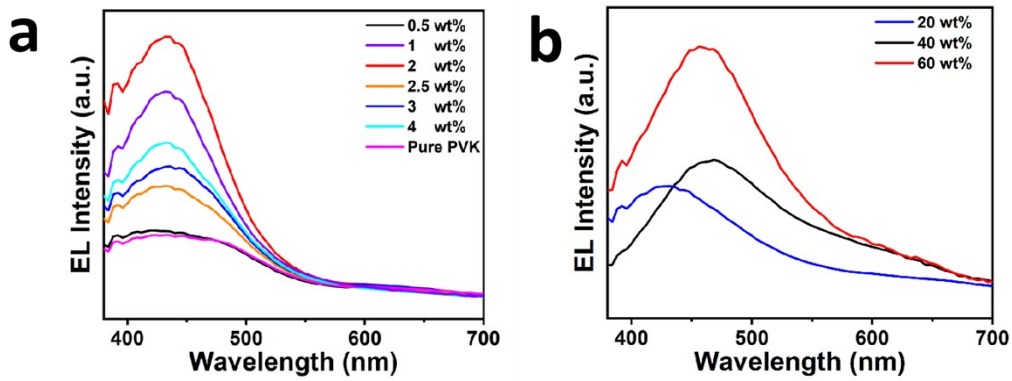

Figure S4. EL spectra of CDs mixed in PVK with different contents of CDs to PVK mass ratios. a) A small number of CDs doped in PVK. b) A large number of CDs doped in PVK.

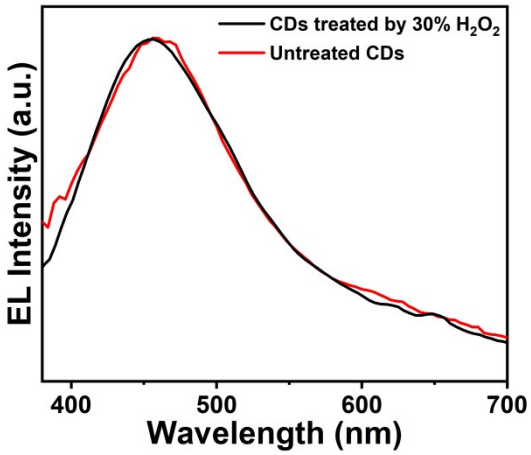

Figure S5. EL spectra of untreated CDs and the CDs treated by 30% H_2O_2.

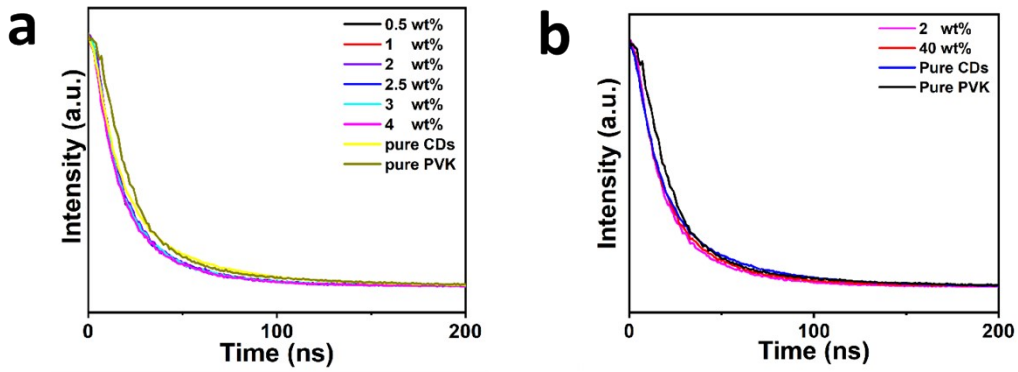

Figure S6. The time resolved PL spectra of CDs doped in PVK with different mass fraction. (a) Low mass fraction. (b) high mass fraction.

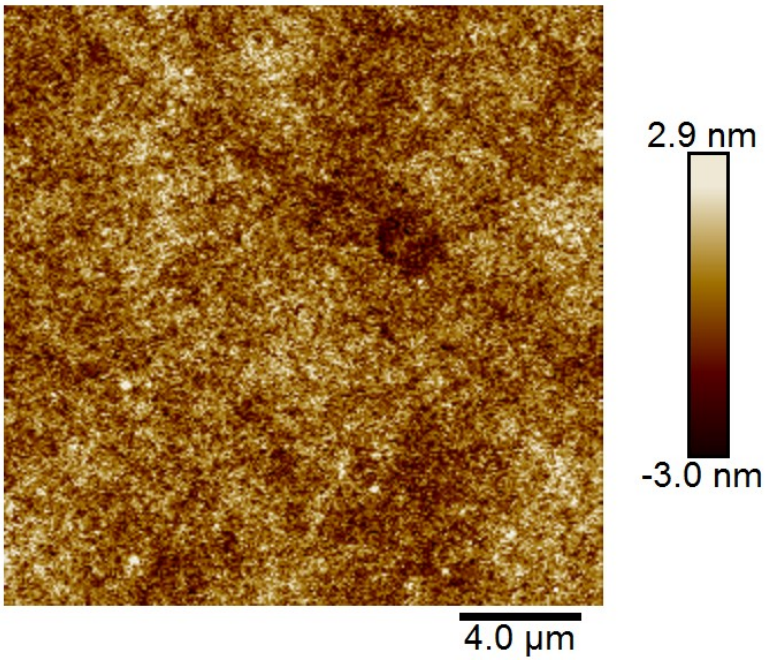

Figure S7. The AFM image of the surface of CDs-LEDs.

Table S1. Comparison of important coefficients of LED based on quantum dots, carbon dots.

Emitter	Structure	EL (nm)	Half lifetime (h)	Max.EQE (%)	Reference
Violet Carbon dot	QDs	408	50	0.831	S1
O, N Co-Doped Carbon Dots	QDs	452	200	2.114	S2
Graphene Quantum Dots	QDs	white	/	0.2	S3
Deep-blue carbon dot	QDs	450	3	4	S4
Carbon Dot	QDs	474	/	/	S5
Carbon Emitters	Thin firm	498	/	/	S6
This work	QDs	456	Over 217	0.856	This work

Reference:

S1. X. Wang, X. Zhang, X. Gu, H. Nie, M. Zhu, B. Wang, J. Gao, Y. Tao, Y. Zhu, H. Huang, C. Xu, M. Shao, Y. Liu, L. Liao and Z. Kang, *Adv. Opt. Mater.*, 2020, **8**, 2000239.

S2. X. Wang, Y. Ma, Q. Wu, Z. Wang, Y. Tao, Y. Zhao, B. Wang, J. Cao, H. Wang, X. Gu, H. Huang, S. Li, X. Wang, F. Hu, M. Shao, L. Liao, T. K. Sham, Y. Liu and Z. Kang, *Laser Photonics Rev.*, 2021, **15**, 2000412.

S3. Z. Luo, G. Qi, K. Chen, M. Zou, L. Yuwen, X. Zhang, W. Huang and L. Wang, *Adv. Funct. Mater*., 2016, **26**, 2739-2744.

S4. F. Yuan, Y.-K. Wang, G. Sharma, Y. Dong, X. Zheng, P. Li, A. Johnston, G. Bappi, J. Z. Fan, H. Kung, B. Chen, M. I. Saidaminov, K. Singh, O. Voznyy, O. M. Bakr, Z.-H. Lu and E. H. Sargent, *Nat. Photonics*, 2019, **14**, 171-176.

S5. J. Xu, Y. Miao, J. Zheng, Y. Yang and X. Liu, *Adv. Opt. Mater.*, 2018, **6**, 1800181.

S6. A. Singh, A. Wolff, S. D. Yambem, M. Esmaeili, J. D. Riches, M. Shahbazi, K. Feron, E. Eftekhari, K. K. Ostrikov, Q. Li and P. Sonar, *Adv. Mater.*, 2020, **32**, 1906176.