

Supporting Information

Revealing Graphitic Nitrogen Participating in p- π Conjugated Domain as Emissive Center of Red Carbon Dots and Applied to Red Room- Temperature Phosphorescence

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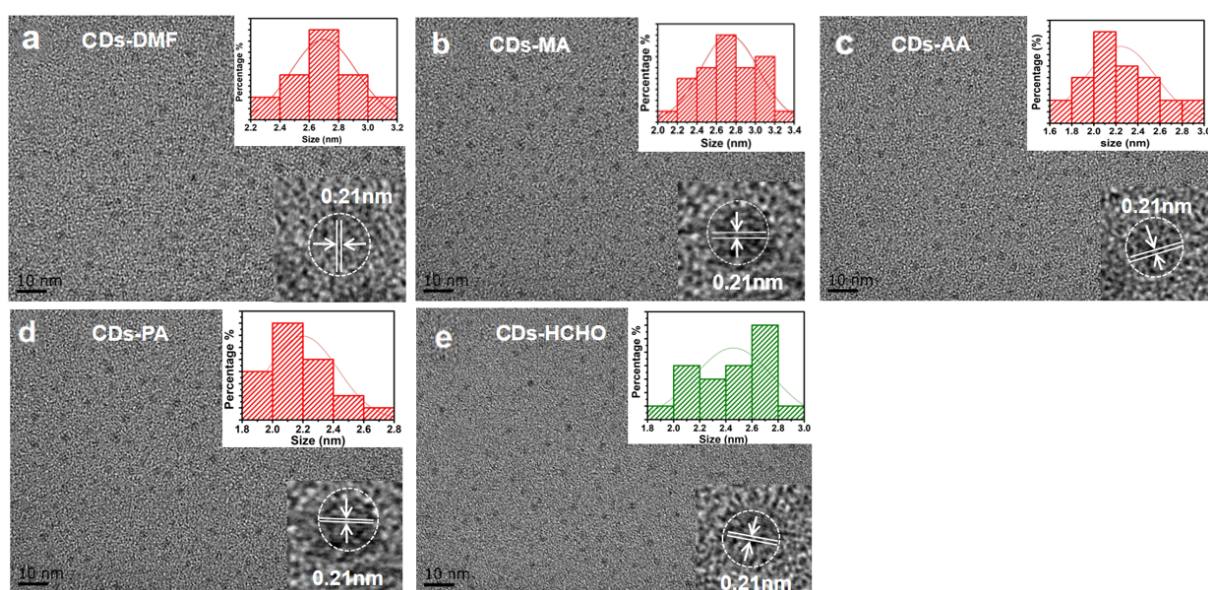


Figure S1. TEM images of (a) CDs-DMF, (b) CDs-MA, (c) CDs-AA, (d) CDs-PA, (e) CDs-HCHO. The insets are respectively HRTEM images and particle size distributions.

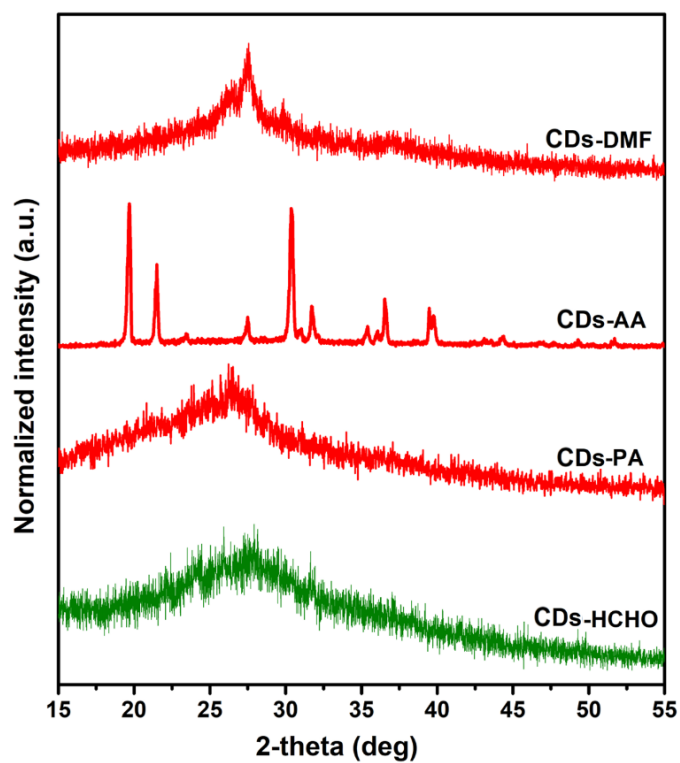


Figure S2. XRD patterns of CDs-DMF, CDs-AA, CDs-PA and CDs-HCHO.

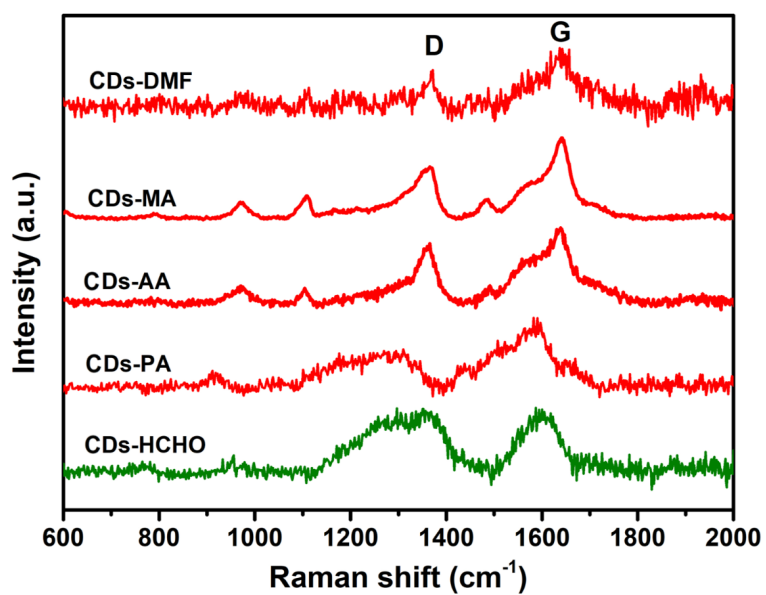


Figure S3. Raman spectra of CDs-DMF, CDs-MA, CDs-AA, CDs-PA and CDs-HCHO.

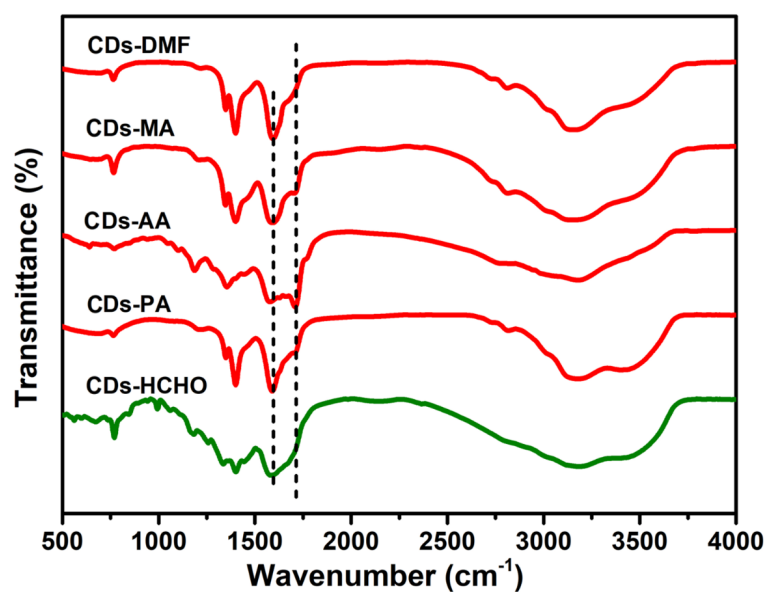


Figure S4. FT-IR spectra of CDs-DMF, CDs-MA, CDs-AA, CDs-PA and CDs-HCHO.

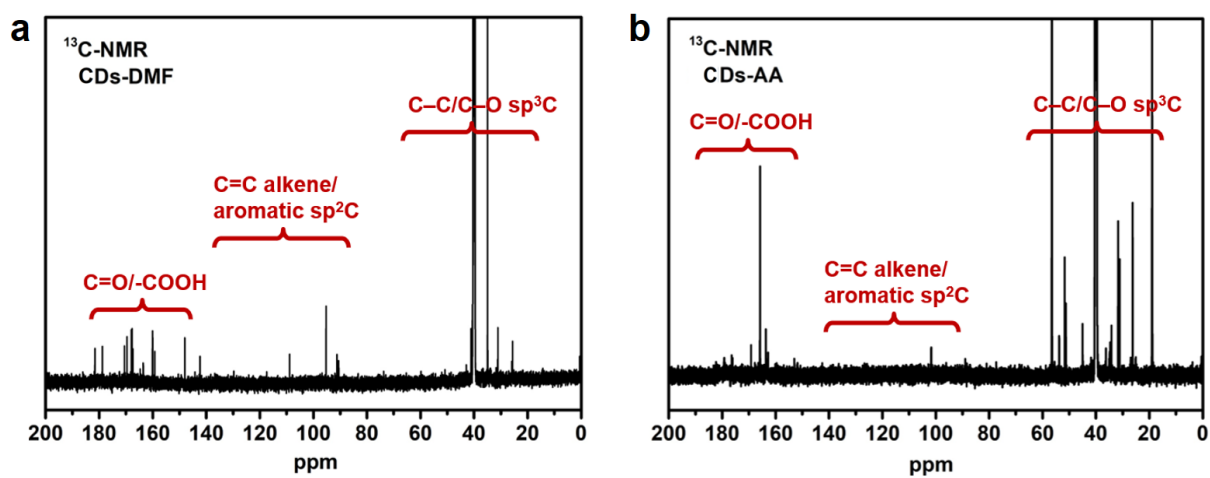


Figure S5. ^{13}C NMR spectra of (a) CDs-DMF and (b) CDs-AA.

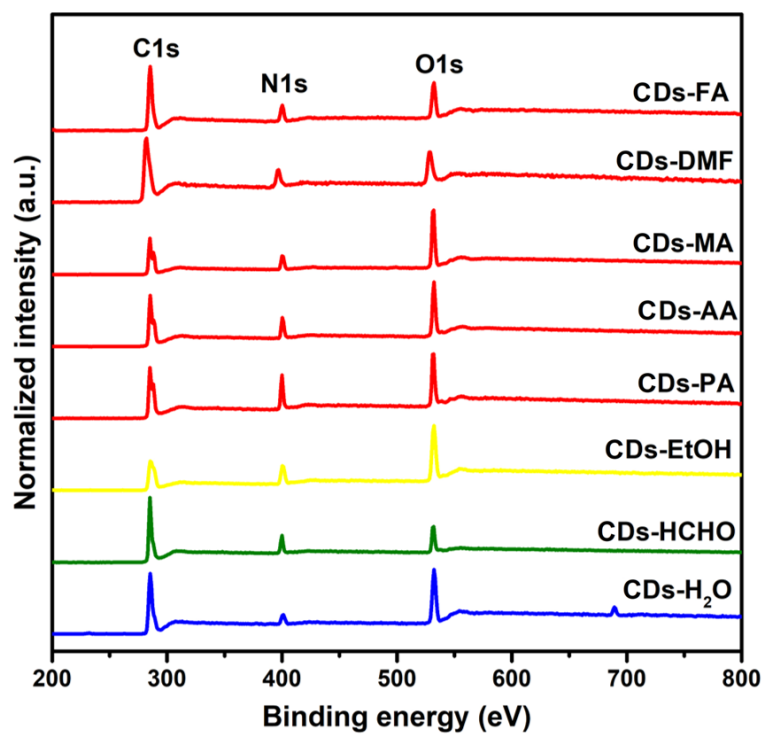


Figure S6. XPS (full survey, C1s, N1s, O1s) of CDs-FA, CDs-DMF, CDs-MA, CDs-AA, CDs-PA, CDs-MeOH, CDs-HCHO and CDs-H₂O.

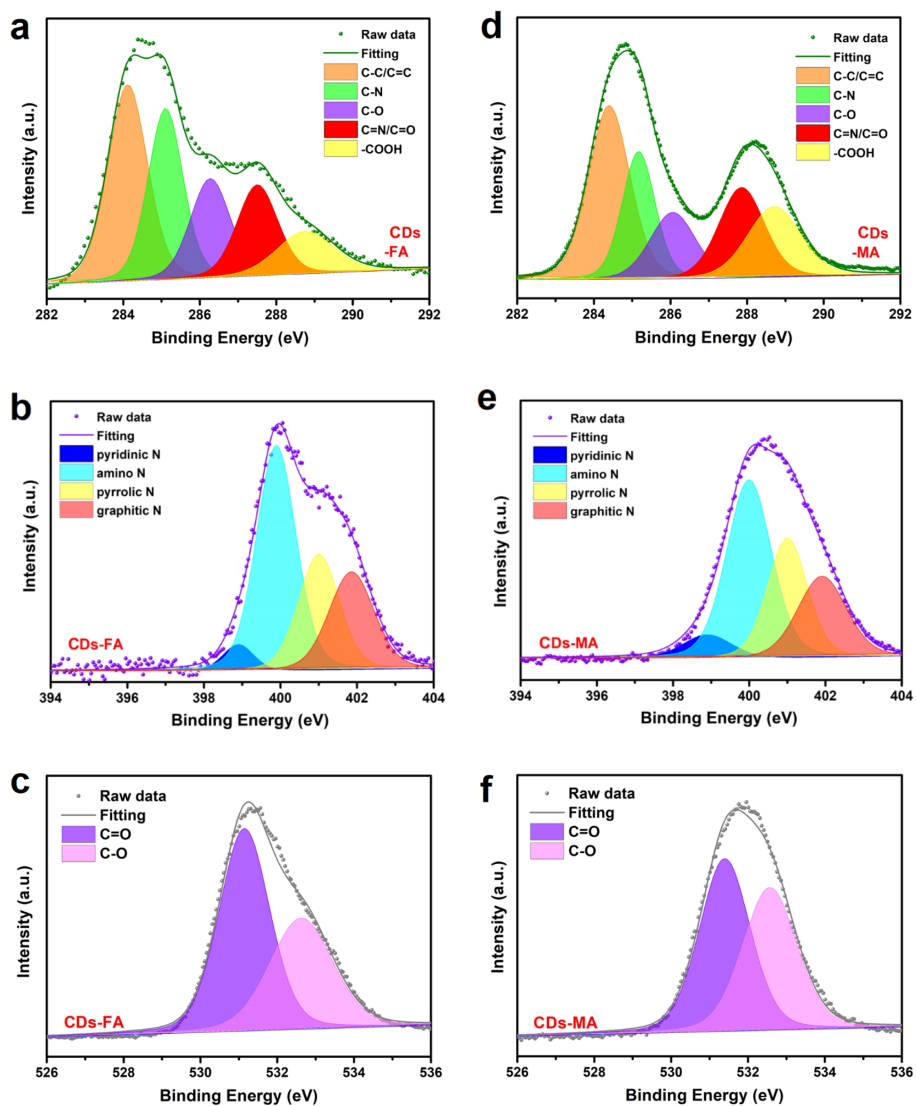


Figure S7. High-resolution spectral fitting analysis corresponding to C1s (a/d), N1s (b/e) and O1s (c/f) of CDs-FA and CDs-MA.

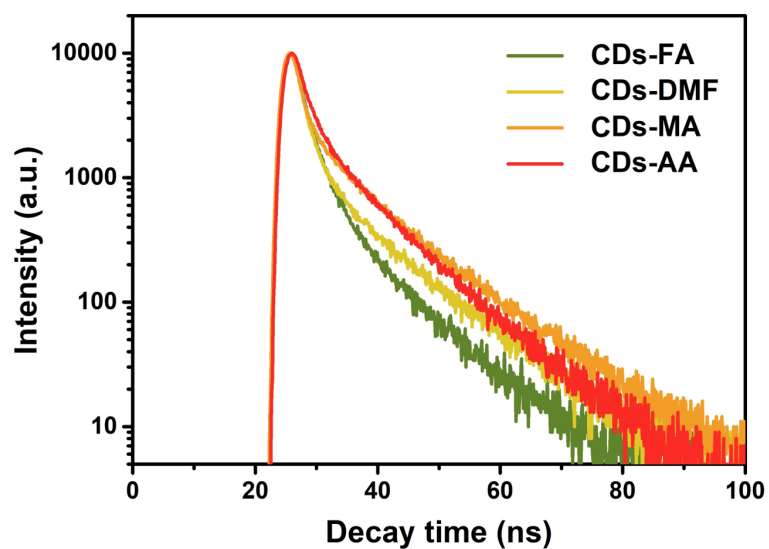


Figure S8. FL lifetime decay curves of the CDs-FA, CDs-DMF, CDs-MA and CDs-AA.

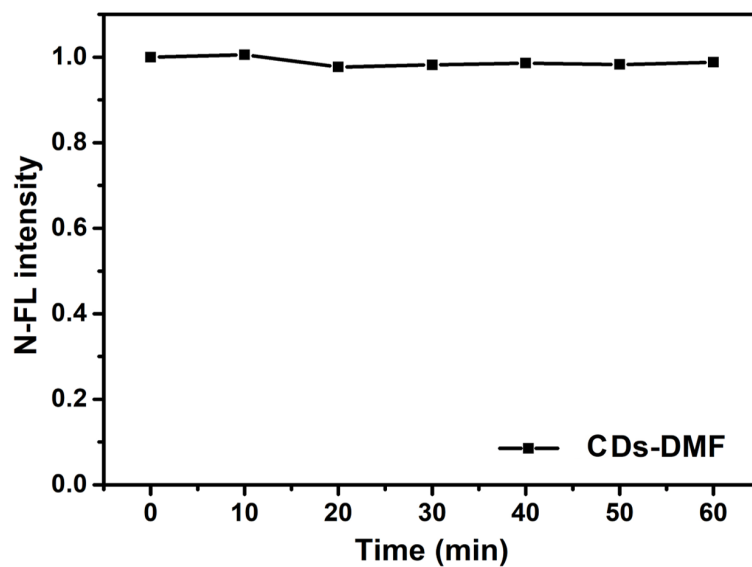


Figure S9. Photostability of red-emissive CDs-DMF under continuous irradiation by 150W xenon lamp.

Table S1. Synthesis of CDs by solvothermal treatment in different solvents with citric acid and formamide as reaction precursors.

Sample	Carbon source	Nitrogen source	Solvent (10mL)	Reaction conditions	Luminescent color (emission)
CDs-FA	Citric acid (1g)	Formamide (1.4mL)	Formamide	Solvothermal 180°C 4h	Red (650 nm)
CDs-DMF			DMF		Red (645 nm)
CDs-MA			Methanoic acid		Red (650 nm)
CDs-AA			Acetic acid		Red (660 nm)
CDs-PA			Propanone		Red (645 nm)
CDs-MeOH			Methyl alcohol		Yellow (580 nm)
CDs-HCHO			Formaldehyde		Green (550 nm)
CDs-H ₂ O			Water		Blue (460 nm)

Table S2. The detailed relative contents of C, N, O and the O/C, N/C and N/O ratio of CDs-FA, CDs-DMF, CDs-MA, CDs-AA, Ds-PA, CDs-MeOH, CDs-HCHO and CDs-H₂O.

Sample	C (mol %)	N (mol %)	O (mol %)	N/C (%)	O/C (%)	N/O (%)
CDs-FA	73.95	10.52	15.53	0.14	0.21	0.68
CDs-DMF	75.98	10.76	13.26	0.14	0.17	0.81
CDs-MA	57.59	12.05	30.38	0.21	0.53	0.40
CDs-AA	63.67	13.13	23.19	0.21	0.36	0.57
CDs-PA	61.10	17.65	21.26	0.29	0.35	0.83
CDs-MeOH	58.63	12.5	28.88	0.21	0.49	0.43
CDs-HCHO	78.77	8.83	12.39	0.11	0.16	0.71
CDs-H ₂ O	69.85	7.05	23.1	0.10	0.33	0.31

Table S3. The detailed relative amounts of functional groups of CDs-FA, CDs-DMF, CDs-MA, CDs-AA, CDs-PA, CDs-MeOH, CDs-HCHO and CDs-H₂O.

	CDs-FA	CDs-DMF	CDs-MA	CDs-AA	CDs-PA	CDs-MeOH	CDs-HCHO	CDs-H ₂ O
C-C/C=C (eV/%)	284.2	284.2	284.4	284.3	284.3	284.4	284.5	284.4
	36.2	36.7	32.3	33.8	26.0	25.2	41.6	48.0
C-N (eV/%)	285.2	285.2	285.2	285.2	285.1	285.2	285.2	285.2
	22.9	23.4	20.9	21.7	22.4	27.4	31.3	27.9
C-O (eV/%)	286.3	286.2	286.1	286.2	286.1	286.2	286.2	286.2
	16.5	14.1	13.5	13.5	16.6	16.5	13.3	12.4
C=N/C=O (eV/%)	287.6	287.6	287.8	287.7	287.6	287.3	287.4	287.4
	13.0	14.1	16.4	15.7	18.7	5.9	4.2	2.7
-COOH (eV/%)	288.8	288.8	288.7	288.6	288.6	288.6	288.6	288.6
	11.4	11.7	16.9	15.2	16.3	25.0	9.6	9.0
C=O (eV/%)	531.2	531.4	531.4	531.4	531.2	531.2	531.4	530.9
	59.3	57.0	53.1	53.4	63.4	34.6	59.8	58.7
C-O (eV/%)	532.6	532.8	532.6	532.6	531.2	532.4	532.6	532.2
	40.7	43.0	46.9	46.6	68.5	31.5	40.2	41.3
pyridinic N (eV/%)	398.9	398.9	398.9	398.9	398.9	398.3	398.9	398.9
	4.3	6.9	6.5	5.9	4.0	40.3	44.0	6.2
amino N (eV/%)	399.9	399.9	400.0	399.9	399.9	399.6	399.9	399.8
	47.4	50.3	44.8	46.3	44.0	33.8	37.7	67.2
pyrrolic N (eV/%)	401.0	400.9	401.0	400.7	400.9	400.7	400.8	400.7
	25.0	22.7	26.6	21.6	27.2	15.3	15.6	20.4
graphitic N (eV/%)	401.8	401.7	401.9	401.9	401.8	401.6	402.0	402.0
	23.3	20.0	22.1	26.2	24.7	10.6	2.8	6.1

Table S4. Biexponential Fitting Results of PL Decays for CDs-FA, CDs-DMF, CDs-MA and CDs-AA.

Samples	τ_1 (10^{-9} s)	τ_2 (10^{-9} s)	A ₁ (%)	A ₂ (%)	τ_{avg} (10^{-9} s)
CDs-FA	0.81	5.42	77.6	22.6	1.88
CDs-DMF	0.86	5.37	88.2	11.8	1.42
CDs-MA	1.04	4.77	75.8	23.2	1.95
CDs-AA	0.97	4.21	89.1	10.9	1.33

Table S5. QYs of Rhodamine 6G and CDs-FA, CDs-DMF, CDs-MA, CDs-AA, CDs-PA, CDs-MeOH, CDs-HCHO and CDs-H₂O under corresponding excitation wavelengths.

Samples	Solvent	λ_{exc} /nm	QY ₁	QY ₂	QY ₃	QY ₄	QY ₅	QY _{avg}
Rhodamine 6G	EtOH	488	82%	82%	83%	82%	83%	82.4%
CDs-FA	H ₂ O	550	22.8%	22.5%	21.3%	22.8%	23.1%	22.5%
CDs-DMF	H ₂ O	550	24.3%	27.3%	28.9%	29.8%	28.9%	27.8%
CDs-MA	H ₂ O	550	14.6%	15.9%	15.5%	13.8%	14.4%	14.8%
CDs-AA	H ₂ O	550	16.5%	16.1%	17.1%	17.9%	17.4%	17.0%
CDs-PA	H ₂ O	550	20.2%	21.4%	20.6%	20.8%	21.9%	21.0%
CDs-MeOH	H ₂ O	510	27.5%	28.2%	28.5%	26.1%	27.8%	27.6%
CDs-HCHO	H ₂ O	480	19.5%	20.5%	22.0%	21.0%	21.8%	21.0%
CDs-H ₂ O	H ₂ O	380	69.0%	67.2%	67.5%	68.4%	68.8%	68.2%

Table S6. The phosphorescence properties of CDs-based composited materials.

Matrix	Material Name	RTP E _m	Lifetime	Ref.
Polyvinyl alcohol(PVA)	CDs@PVA	450 nm	450 ms	24
Polyurethane(PU)	CDs@PU	500 nm	8.7 ms	25
KAl(SO ₄) ₂ .x(H ₂ O)	CDs@KAl(SO ₄) ₂ .x(H ₂ O)	500 nm	707 ms	26
Nano silica	Si-CD@(Ca/Sr/Ba)SO ₄	518 nm	1070 ms	27
Layered double hydroxides(LDH)	CDs@LDH	525 nm	386 ms	28
Mn-containing open-frame-work matrices	CDs@MnAPO-CJ50	620 nm	10.94 ms	47
Mn-doped zeolite	CDs@Mn-LEV	620 nm	1.814 ms	48
Polyvinyl alcohol(PVA)	R-CDs@PVA	630 nm	19.1 ms	This work