Supplementary Information (SI) for Inorganic Chemistry Frontiers.

Support Information

Enhancing White Light-Emitting Diode Performance with Ultra-Wide Spectrum ZnS:Mn-CDs@SiO_2 Dual Core@Shell Composite

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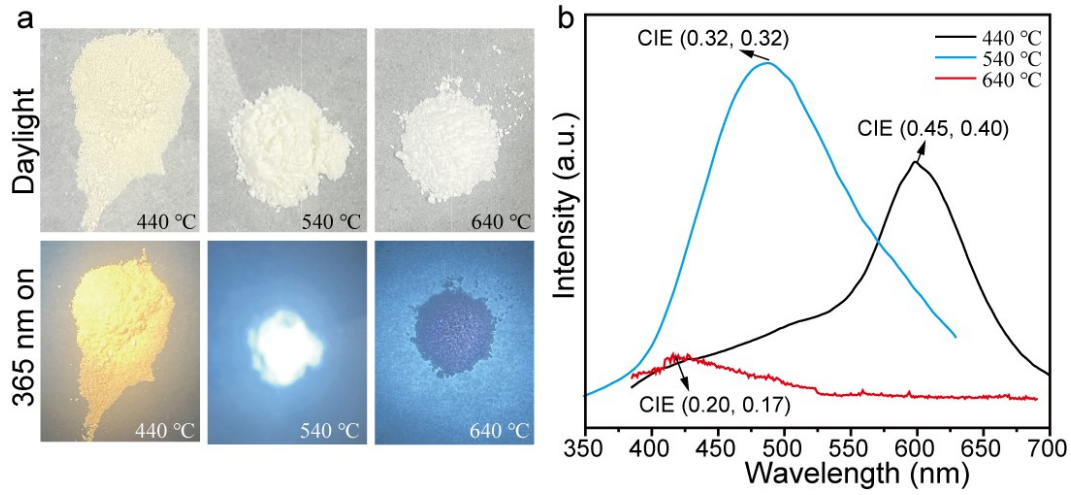

Fig. S1. a) Daylight and UV images, and b) Fluorescence spectra of ZnS:Mn-CDs@SiO2 samples synthesized at 440 ℃, 540 ℃ and 640 ℃ under excitation at 365 nm

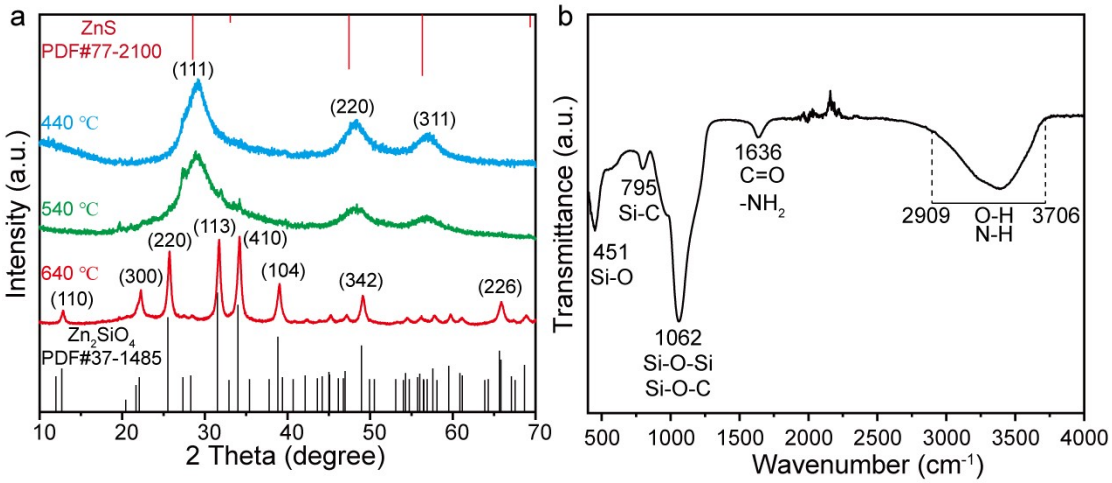

Fig. S2. a) Powder XRD patterns of the as-prepared ZnS:Mn-CDs@SiO_2 at 440 °C, 540 °C and 640 °C and standard card reference data of sphalerite ZnS (red line) and $ZnSiO_4$, b) Fourier transform infrared spectra of as-synthesized ZnS:Mn-CDs@SiO_2.

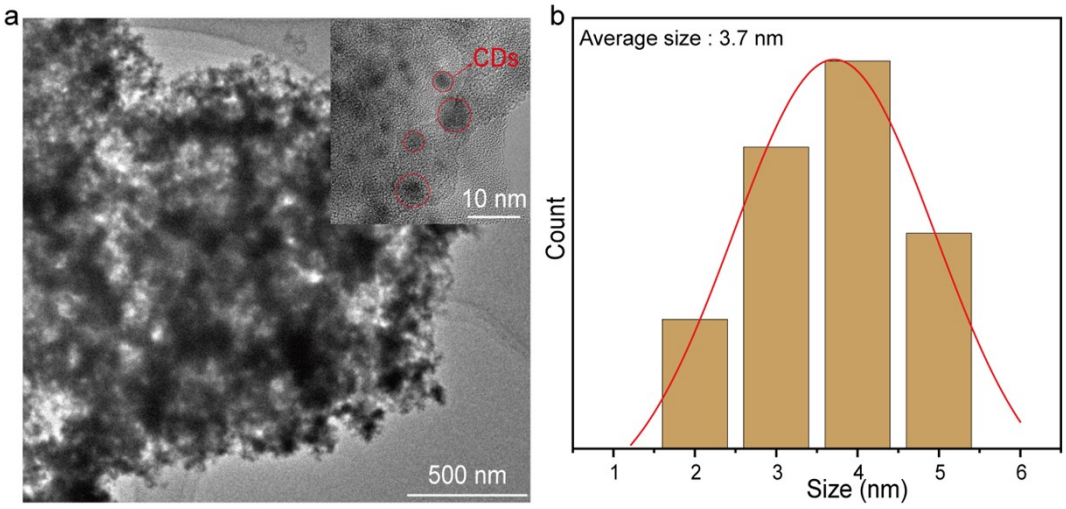

Fig. S3. a) TEM images of ZnS:Mn-CDs@SiO_2 treated with HF acid and b) size distribution histograms of CDs.

In order to exclude the ZnS:Mn component in the ZnS:Mn-CDs@SiO_2 composite for microscopic transmission observation of CDs, we etched the composite material with HF acid. In a typical procedure, 0.15 g of ZnS:Mn-CDs@SiO_2 and 1 mL of HF (8 wt%) were mixed and stirred at 1000 rpm for 4 h. The product was obtained by removing the supernatant and drying at 60 ℃ for 24 hours. Finally, 10 mg of the dried product was redispersed in ethanol for TEM sample preparation.

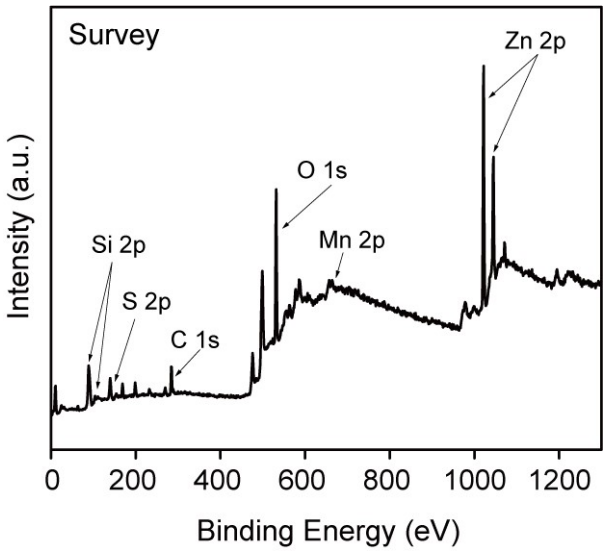

Fig. S4. X-ray Photoelectron Spectroscopy (XPS) survey scan of ZnS:Mn-CDs@SiO_2.

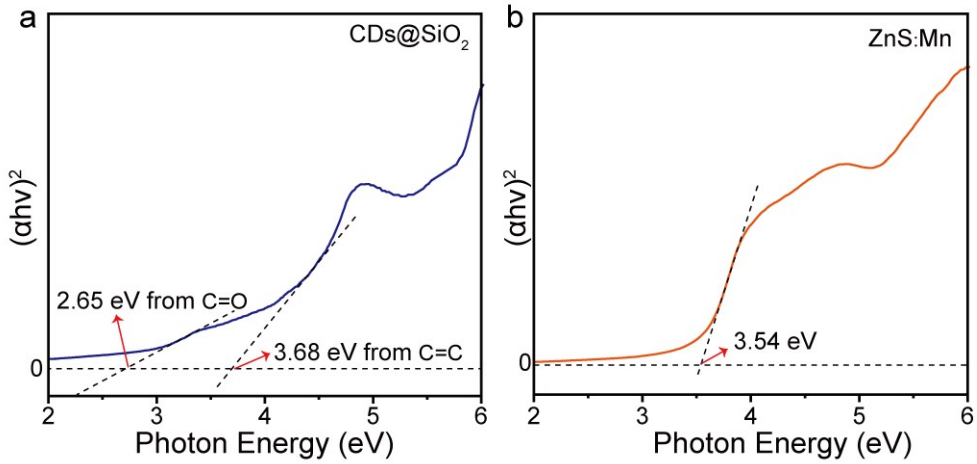

Fig. S5. Tauc plot of the as-prepared: a) CDs@SiO_2, and b)ZnS:Mn nanoscrystals.

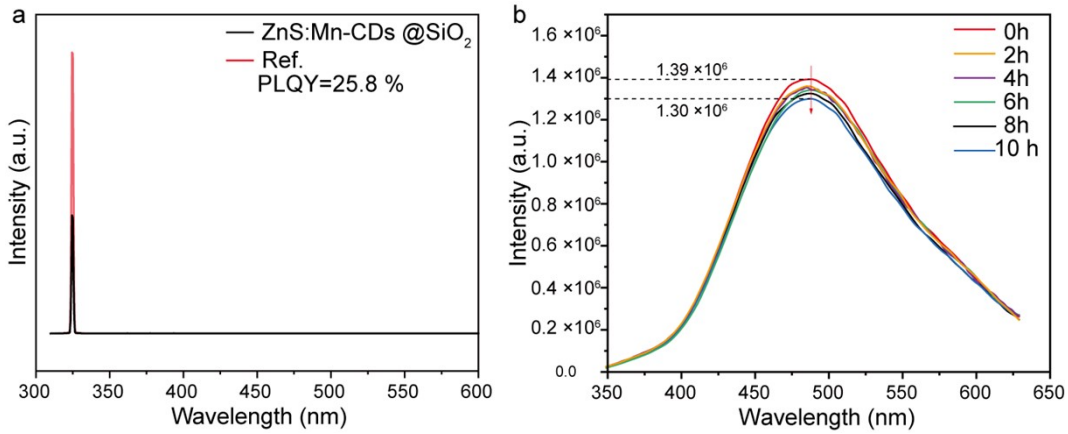

Fig. S6. a) Quantitative photoluminescence spectra of ZnS:Mn-CDs@SiO_2 and the reference for absolute photoluminescence quantum yield (PLQY) determination, and b) the fluorescent intensity of ZnS:Mn-CDs@SiO_2 under 365 nm UV irradiation for different times.

Table S1. The percentage of atoms of ZnS:Mn-CDs@SiO_2 in the X-ray Photoelectron Spectroscopy spectrum.

C 1s (Atomic %)	O 1s (Atomic %)	Si 2p (Atomic %)	Mn 2p (Atomic %)	Zn 2p (Atomic %)	S 2p (Atomic %)
14.3	48.1	29.2	0.5	6.0	1.9

Table S2. Fluorescence lifetime parameters of CDs@SiO_2, ZnS:Mn, and ZnS:Mn-CDs@SiO_2, corresponding to Fig. 3d-f.

Sample	Em(nm)	A_1	τ_1 (ns)	A_2	τ_2 (ns)	r^2
CDs@SiO_2	447	644.71	2.23	275.7	9.3	1.06
ZnS:Mn	602	311.89	2.79	194.59	10.18	1.05
ZnS:Mn-CDs@SiO_2	447	637.34	2.25	379.41	9.92	1.04
	602	344.93	1.54	53.93	10.37	1.08

Table S3. Electroluminescence characteristics of WLED devices based on ZnS:Mn-CDs@SiO_2 materials measured under varying voltages and currents.

Voltage (V)	Current (A)	Luminous flux (Lumen)	CCT (K)	Ra	CRI	Luminous efficiency (Lm/W)	Power efficiency (Watt(O)/Watt(E) %)
3.34	0.08	8.52	5848	76.8	74.2	31.88	40.6
3.39	0.12	12.95	5856	78.3	74.3	31.83	40.6
3.43	0.16	17.46	5859	79.2	74.9	31.81	40.6
-	-	-	5854.3	78.1	74.5	31.84	40.6

Table S4. Performance comparison of our WLED device with other carbon dot WLED devices based on a single matrix

Reference	CRI	CCT	Luminous efficiency (Lm/W)	CIE	Comprehensive evaluation
1	79	5240	5.9	0.34, 0.37	Good color reproduction, but low luminous efficiency
2	77	5893	1.173	0.33, 0.39	Very low luminous efficiency, limits usability
3	85	3032	5.65	0.42, 0.38	High color accuracy, but low CCT and noticeable color shift
4	85.3	8756	18.7	0.268, 0.346	High color accuracy, but very high CCT with color shift
5	68.4	6565	32.26	0.32, 0.33	High luminous efficiency, but low color reproduction
6	71.7	7818	58.14	0.29, 0.33	Highest luminous efficiency, but very high CCT
This Work	74.5	5854.3	31.84	0.32, 0.38	Well-balanced, suitable for general lighting

Notes and references

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