

## Supplementary Information

### Tb<sup>3+</sup>-Tuned Afterglow in CDs@Al<sub>2</sub>O<sub>3</sub> for Dynamic Information Encryption and Slow-Fade Indicators

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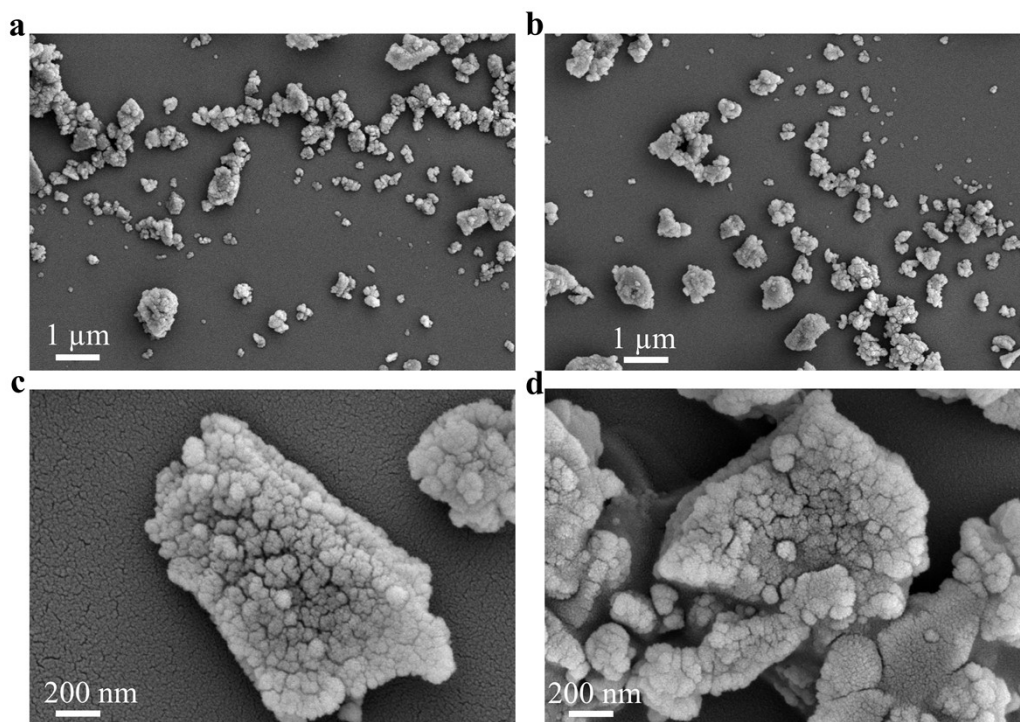
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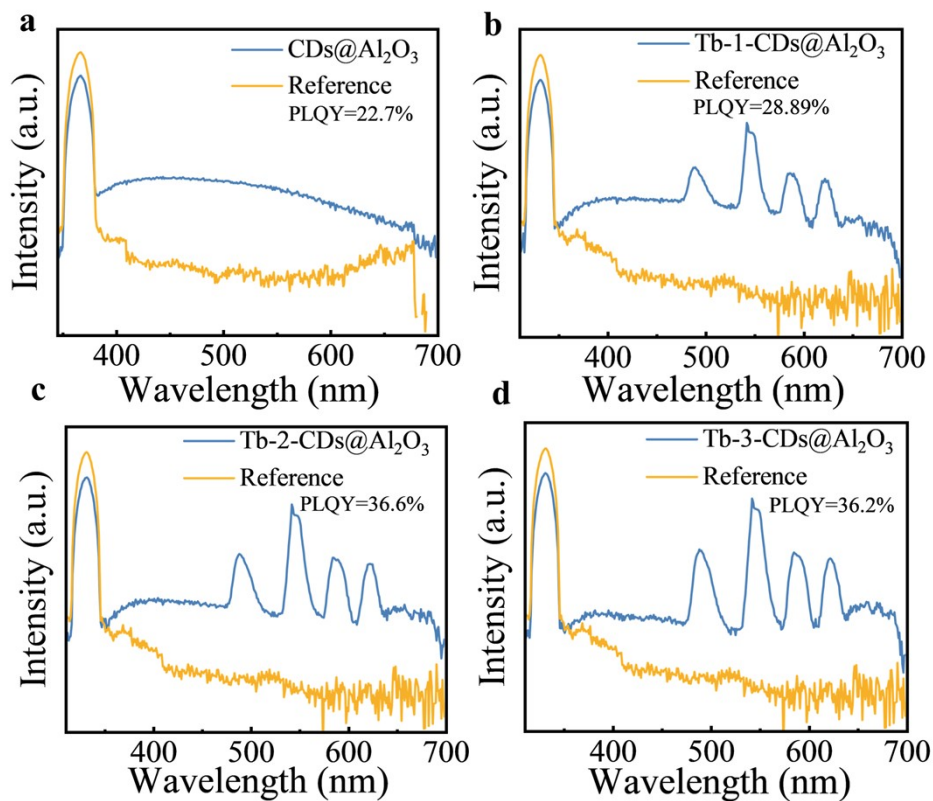
d. Hangzhou City University, Hangzhou 310015, China

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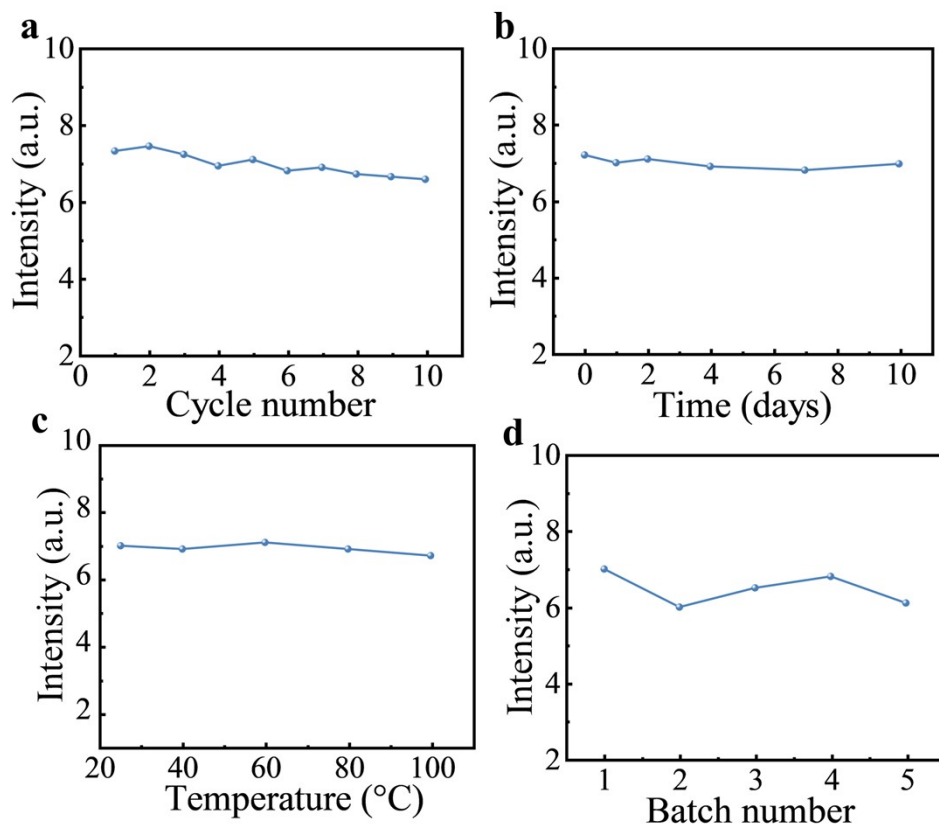
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**Fig. S1.** Comparative SEM images of CDs@Al<sub>2</sub>O<sub>3</sub> and Tb-3-CDs@Al<sub>2</sub>O<sub>3</sub> recorded at matched magnifications. (a, c) CDs@Al<sub>2</sub>O<sub>3</sub>; (b, d) Tb-3-CDs@Al<sub>2</sub>O<sub>3</sub>. Panels (a, b) show low-magnification SEM images, while panels (c, d) show the corresponding high-magnification SEM images.

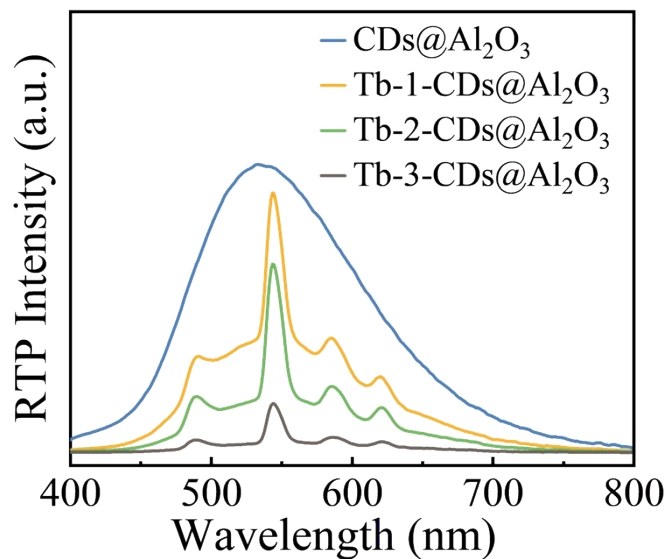


**Fig. S2.** PLQY measurement spectra of (a)  $\text{CDs@Al}_2\text{O}_3$ , (b)  $\text{Tb-1-CDs@Al}_2\text{O}_3$ , (c)  $\text{Tb-2-CDs@Al}_2\text{O}_3$ , and (d)  $\text{Tb-3-CDs@Al}_2\text{O}_3$ .

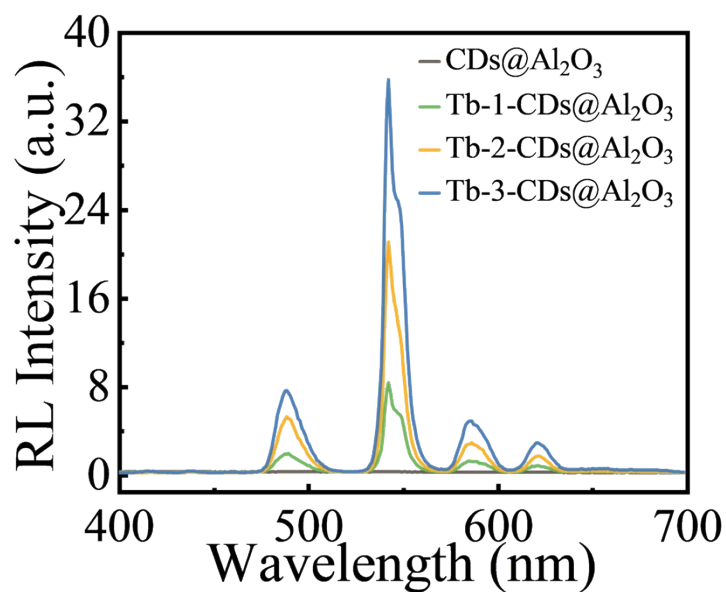


**Fig. S3.** PL stability and reproducibility of  $\text{Tb-2-CDs@Al}_2\text{O}_3$  monitored by the  $\text{Tb}^{3+}$

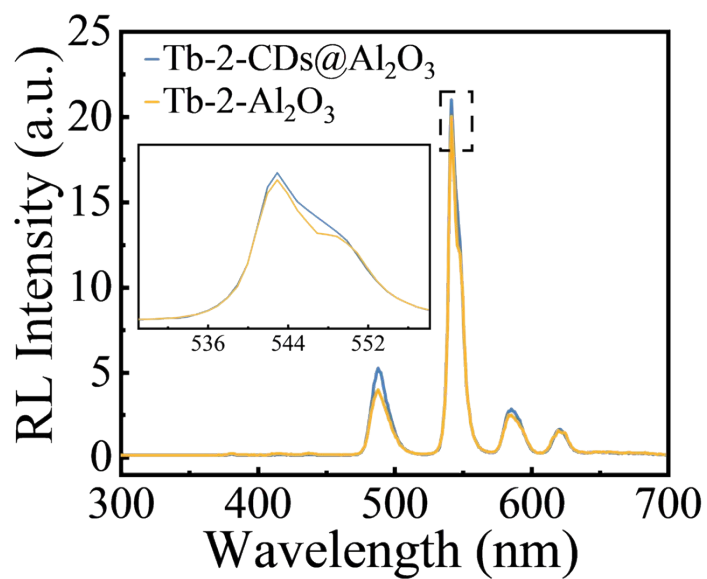
emission at 544 nm under 360 nm excitation: (a) repeated-excitation cycles; (b) 10-day storage; (c) thermal treatment at 25-100 °C; and (d) reproducibility across five batches.



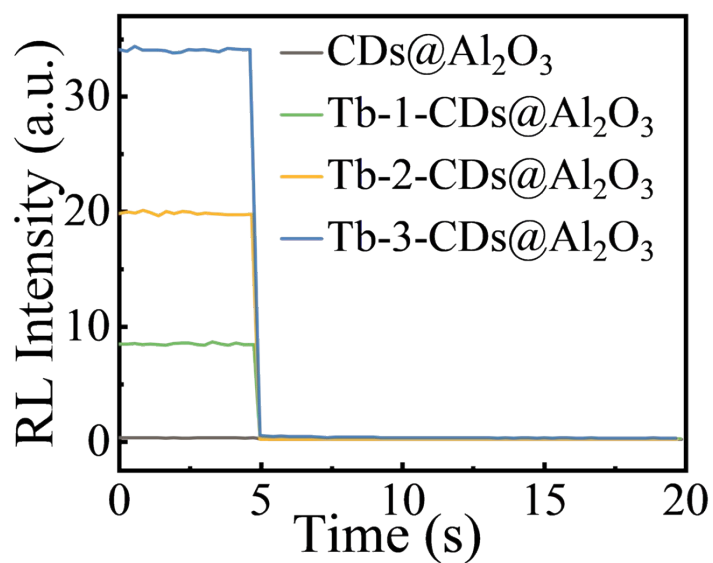
**Fig. S4.** Delayed emission spectra of CDs@Al<sub>2</sub>O<sub>3</sub> and Tb-x-CDs@Al<sub>2</sub>O<sub>3</sub> recorded with a delay time of 1 ms.



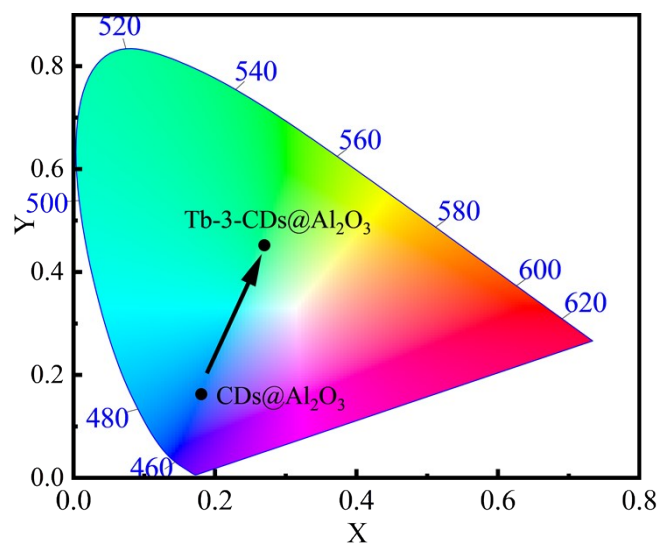
**Fig. S5.** X-ray-excited luminescence spectra of CDs@Al<sub>2</sub>O<sub>3</sub> and Tb-x-CDs@Al<sub>2</sub>O<sub>3</sub>.



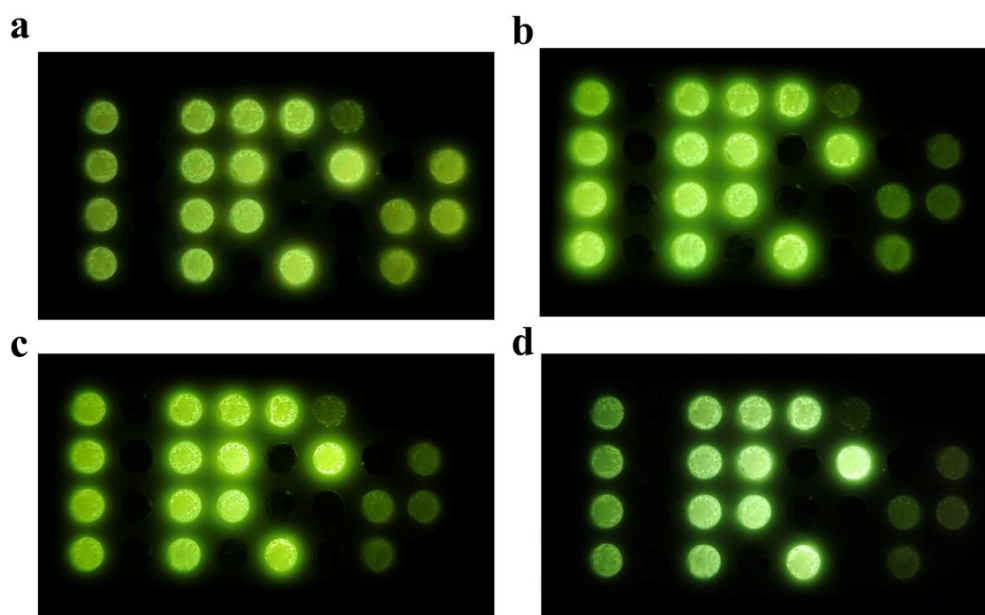
**Fig. S6.** X-ray-excited luminescence spectra of Tb-2-CDs@Al<sub>2</sub>O<sub>3</sub> and Tb-2-Al<sub>2</sub>O<sub>3</sub>.



**Fig. S7.** Time-dependent X-ray-excited luminescence intensity of CDs@Al<sub>2</sub>O<sub>3</sub> and Tb-x-CDs@Al<sub>2</sub>O<sub>3</sub> before and after the X-ray source was switched off.



**Fig. S8.** CIE 1931 chromaticity diagram of the fluorescence emission colors of  $\text{CDs@Al}_2\text{O}_3$  and  $\text{Tb-3-CDs@Al}_2\text{O}_3$ .



**Fig. S9.** Repeated photographic readouts of the same encryption matrix recorded at 1 s after UV off under consistent photographic conditions: (a-d) four independent measurements showing similar luminescence patterns and the same decoded output.

**Table S1.** Actual Tb contents of Tb-x-CDs@Al<sub>2</sub>O<sub>3</sub> determined by ICP-OES.

Sample	Actual Tb content (wt%)
Tb-1-CDs@Al <sub>2</sub> O <sub>3</sub>	2.028 ± 0.014
Tb-2-CDs@Al <sub>2</sub> O <sub>3</sub>	3.709 ± 0.011
Tb-3-CDs@Al <sub>2</sub> O <sub>3</sub>	4.796 ± 0.014

Values are presented as mean ± standard deviation based on three parallel ICP-OES measurements.

**Table S2.** Emission decay lifetimes of CDs@Al<sub>2</sub>O<sub>3</sub> and Tb-x-CDs@Al<sub>2</sub>O<sub>3</sub>.

Sample	lifetime at 415 nm (ns)	lifetime at 544 nm (ms)	RTP lifetime at 534 nm (s)
CDs@Al <sub>2</sub> O <sub>3</sub>	5.20	—	1.20
Tb-1-CDs@Al <sub>2</sub> O <sub>3</sub>	5.10	1.889	1.08
Tb-2-CDs@Al <sub>2</sub> O <sub>3</sub>	4.92	1.930	0.95
Tb-3-CDs@Al <sub>2</sub> O <sub>3</sub>	4.35	1.861	0.82

**Table S3.** Lifetime-Derived Apparent ET Efficiency

Sample	$\tau_{RTP}$ (s)	$\eta_{ET}$ (%)
CDs@Al <sub>2</sub> O <sub>3</sub>	1.20	0
Tb-1-CDs@Al <sub>2</sub> O <sub>3</sub>	1.08	10
Tb-2-CDs@Al <sub>2</sub> O <sub>3</sub>	0.95	20.8
Tb-3-CDs@Al <sub>2</sub> O <sub>3</sub>	0.82	31.7

The lifetime-derived apparent energy-transfer efficiency from the CDs triplet state was estimated according to:

$$\eta_{ET} = 1 - \frac{\tau_{DA}}{\tau_D}$$

where  $\tau_D$  is the RTP lifetime of CDs@Al<sub>2</sub>O<sub>3</sub>, and  $\tau_{DA}$  is the RTP lifetime of Tb-x-CDs@Al<sub>2</sub>O<sub>3</sub> at a given nominal Tb<sup>3+</sup> loading.