Supporting Information

Upconversion phosphors of $CaLaAl_3O_7:RE^{3+}/Yb^{3+}$ (RE=Tm, Ho) and their multifunctional applications for multi-color anti-counterfeiting and laser displays

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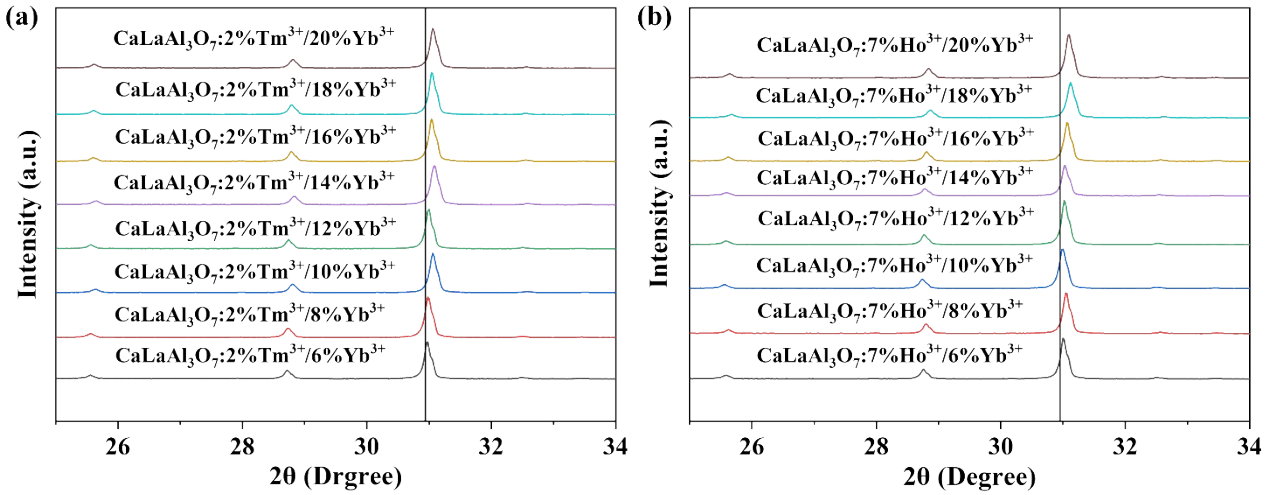

Fig. S1 XRD patterns peak shifts: **(a)** $CaLaAl_3O_7:2\%Tm^{3+}/z_1\%Yb^{3+}$ (z_1 = 6, 8, 10, 12, 14, 16, 18, 20) powder samples **(b)** $CaLaAl_3O_7:7\%Ho^{3+}/z_2\%Yb^{3+}$ (z_2 = 6, 8, 10, 12, 14, 16, 18, 20) powder samples.

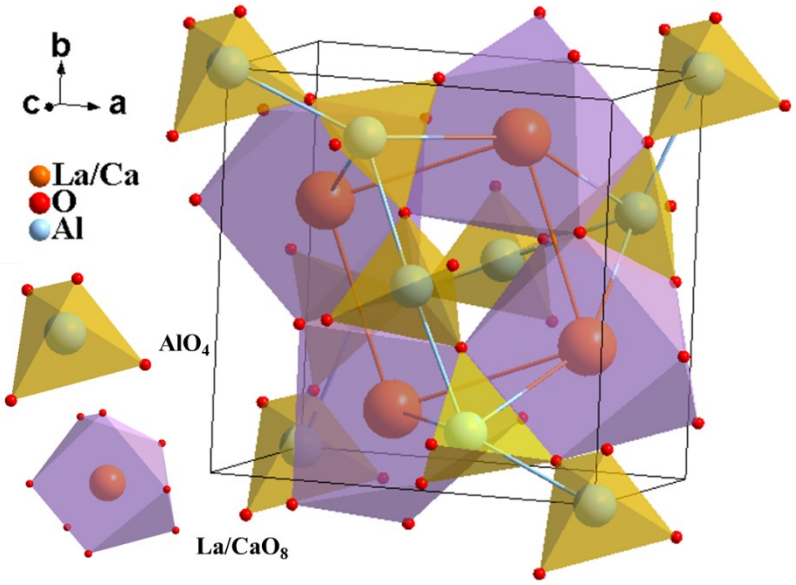

Fig. S2 Crystal structure information of the $CaLaAl_3O_7$ matrix.

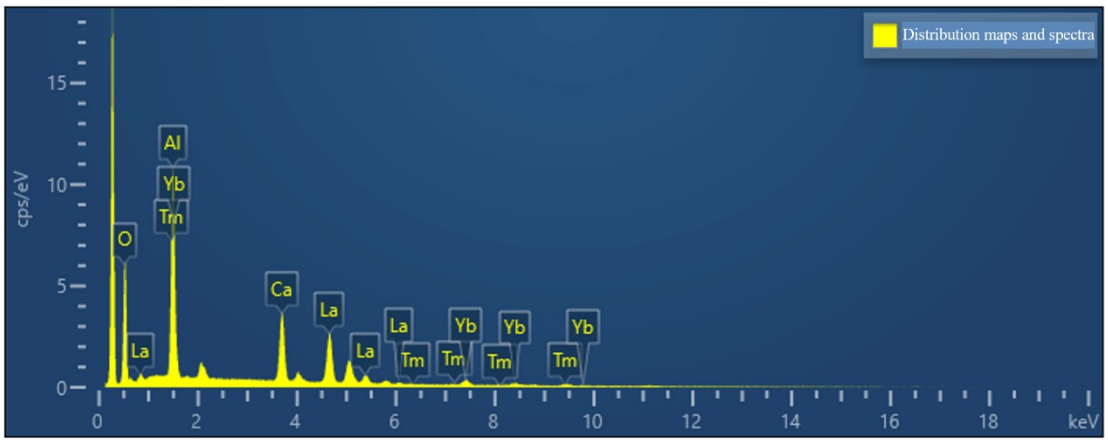

Fig. S3 EDS element distribution of the $CaLaAl_3O_7$:2%Tm^{3+}/18%Yb^{3+} phosphor.

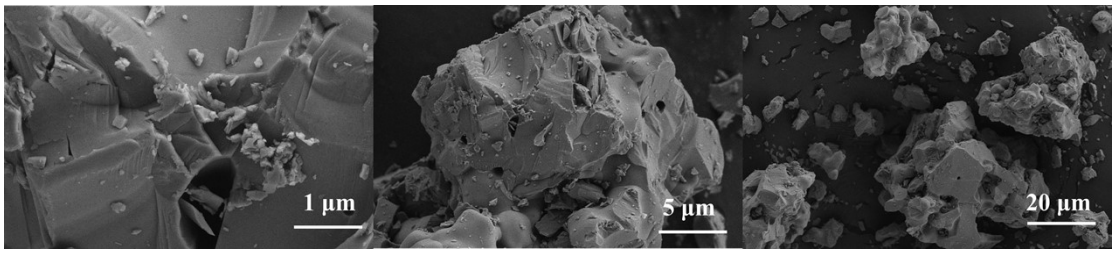

Fig. S4 SEM images of the $CaLaAl_3O_7$:2%Tm^{3+}/18%Yb^{3+} representative at different magnifications.

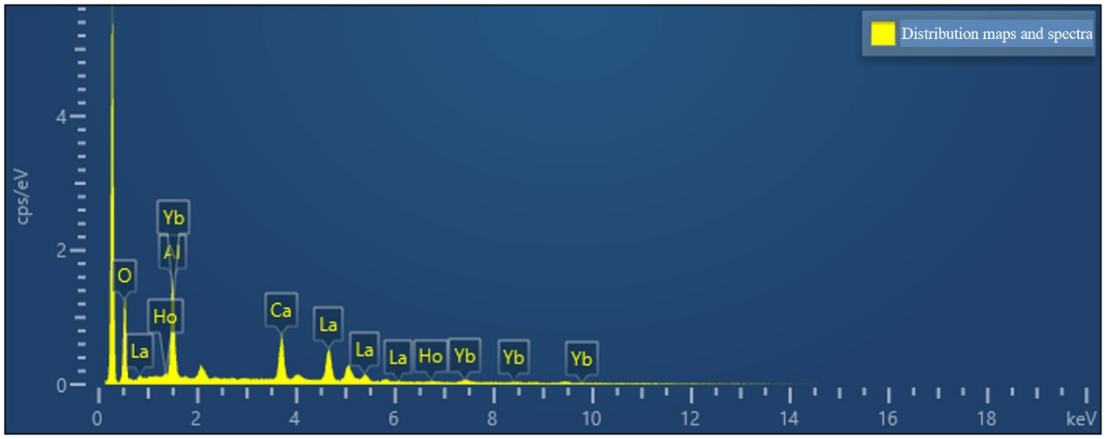

Fig. S5 EDS element distribution of the $CaLaAl_3O_7$:7%Ho^{3+}/14%Yb^{3+} phosphor.

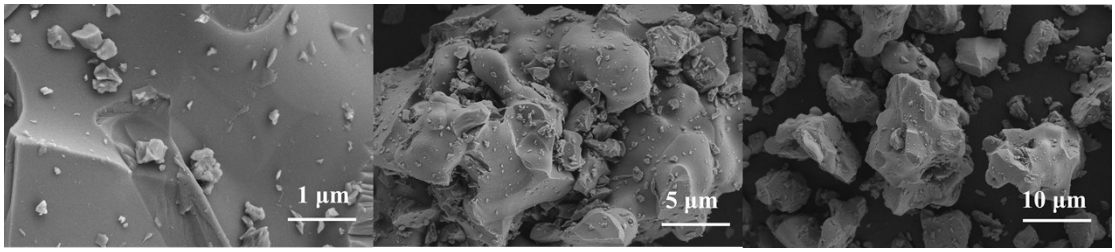

Fig. S6 SEM images of the $CaLaAl_3O_7$:7%Ho^{3+}/14%Yb^{3+} representative at different magnifications.

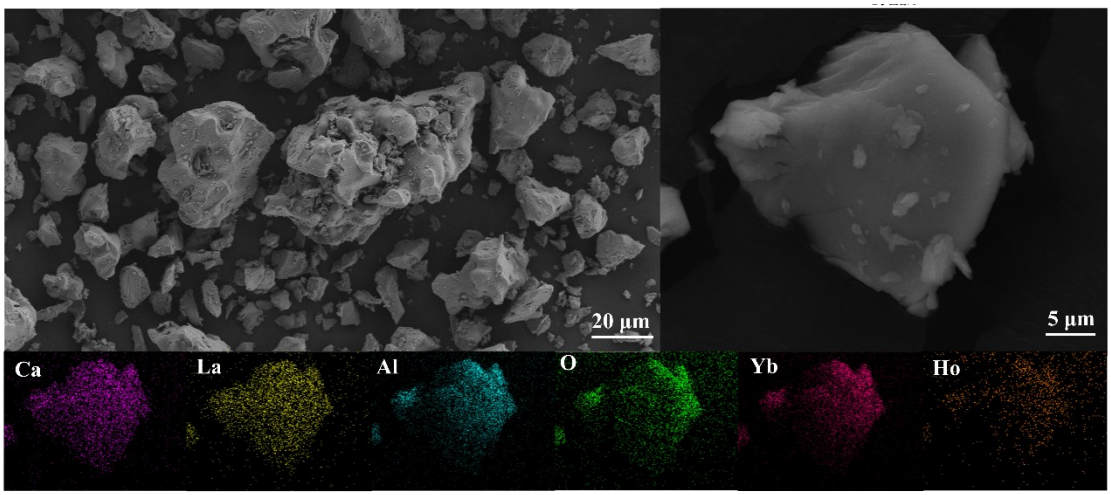

Fig. S7 SEM photograph and EDS elemental mapping image of the $CaLaAl_3O_7$:7%Ho^{3+}/14%Yb^{3+} phosphor.

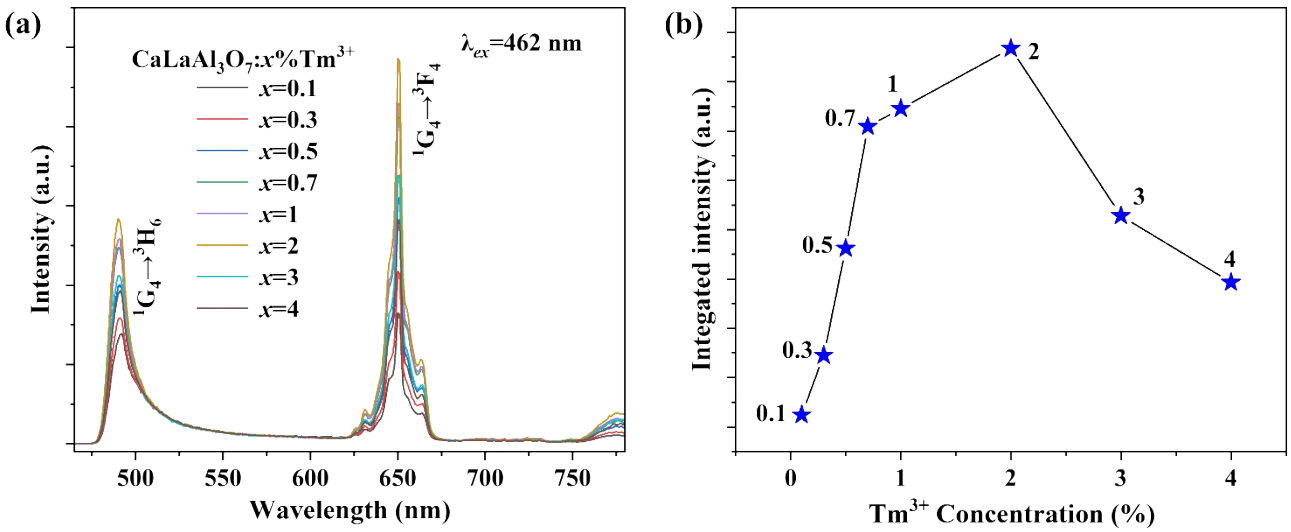

Fig. S8 (a) PL of $CaLaAl_3O_7$:x%Tm^{3+} (x = 0.1, 0.3, 0.5, 0.7, 1, 2, 3, 4) phosphors; (b) Upconversion luminescence integrated intensity in the range of 625–675 nm varyings with Tm^{3+} concentration

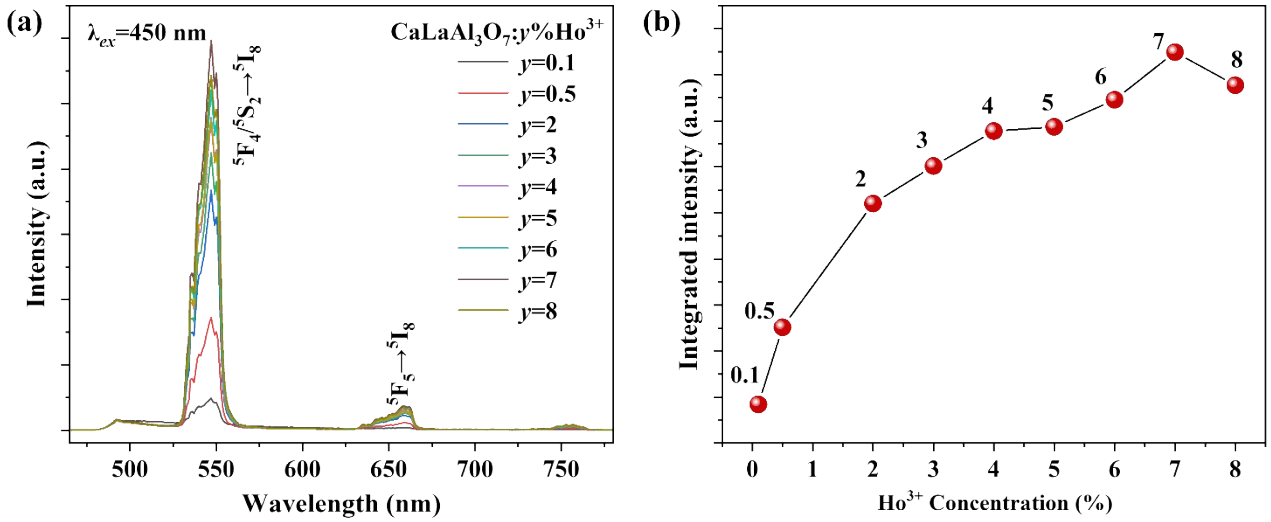

Fig. S9 (a) PL of $CaLaAl_3O_7$:y%Ho^{3+} (y = 0.1, 0.5, 2, 3, 4, 5, 6, 7, 8) phosphors; (b) Upconversion luminescence integrated intensity in the range of 528–560 nm varying with Ho^{3+} concentration

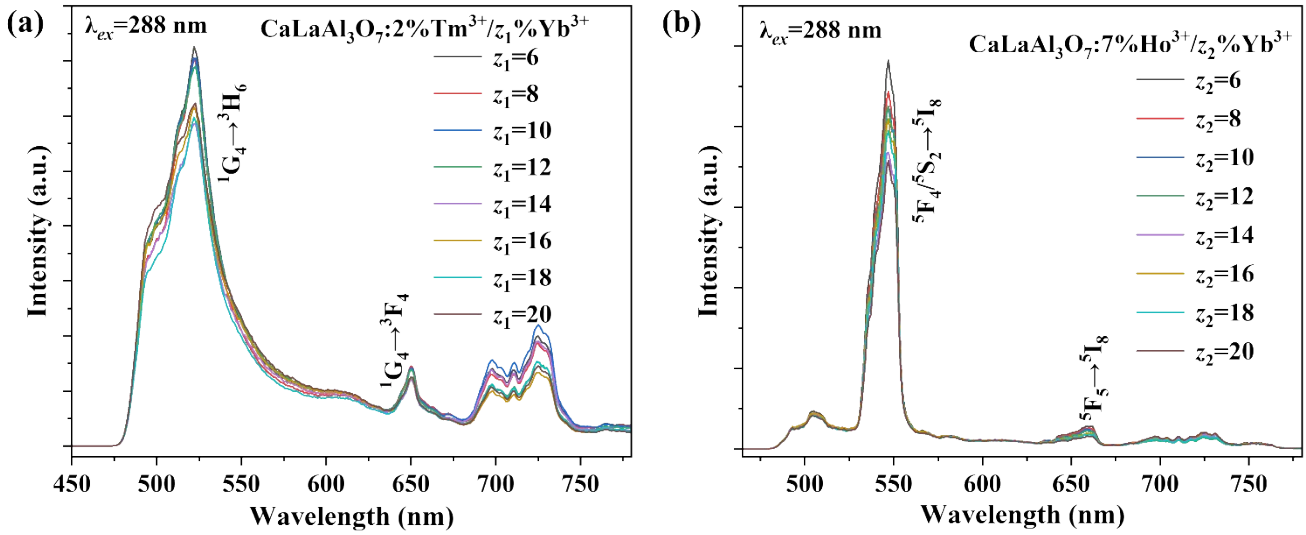

Fig. S10 (a) PL of $CaLaAl_3O_7$:2%Tm^{3+}/$z_1$$Yb^{3+}$ (z_1 = 6, 8, 10, 12, 14, 16, 18, 20) phosphors under 288 nm excitation; (b) PL of $CaLaAl_3O_7$:7%Ho^{3+}/$z_2$$Yb^{3+}$ (z_2 = 6, 8, 10, 12, 14, 16, 18, 20) phosphors under 288 nm excitation

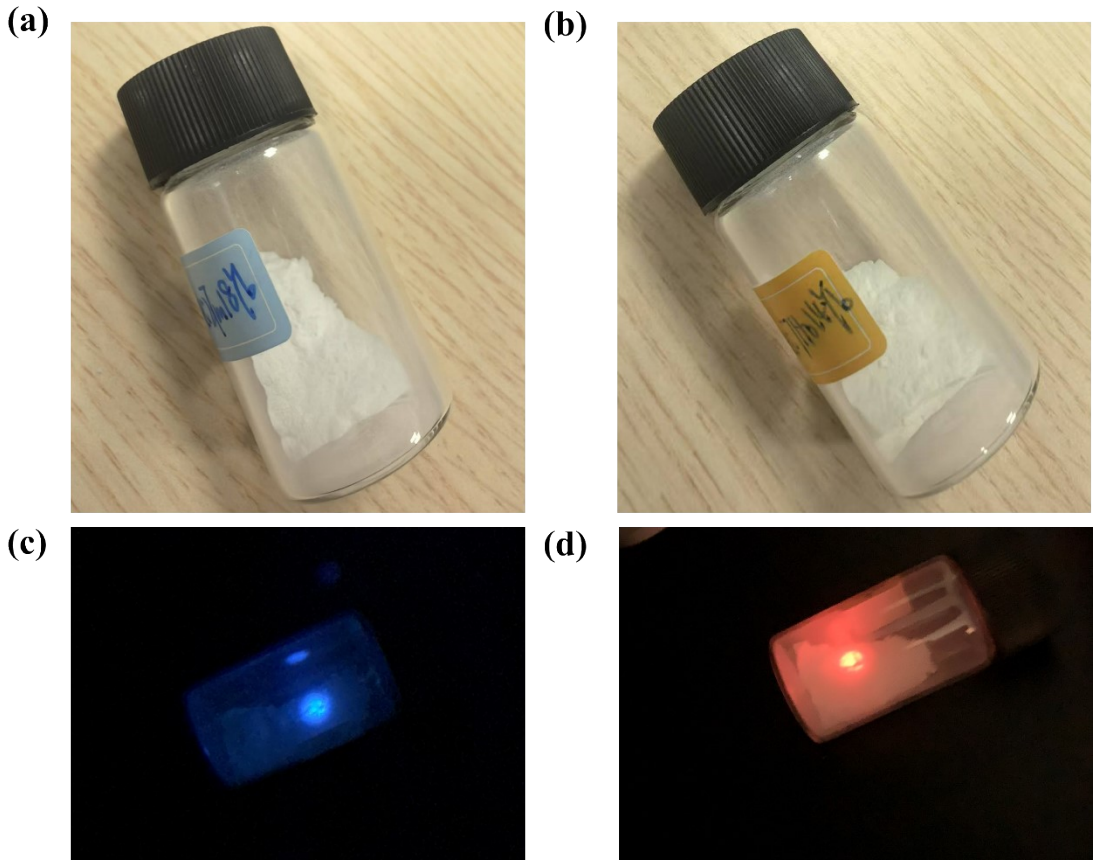

Fig. S11 (a) $CaLaAl_3O_7$:2%Tm^{3+}/18Yb^{3+} sample under natural light; (b) $CaLaAl_3O_7$:7%Ho $^{3+}$/14Yb^{3+} phosphor under natural light; (c) $CaLaAl_3O_7$:2%Tm^{3+}/18Yb^{3+} sample under 98 0 nm laser excitation; (d) $CaLaAl_3O_7$:7%Ho^{3+}/14Yb^{3+} phosphor under 980 nm laser ex citation

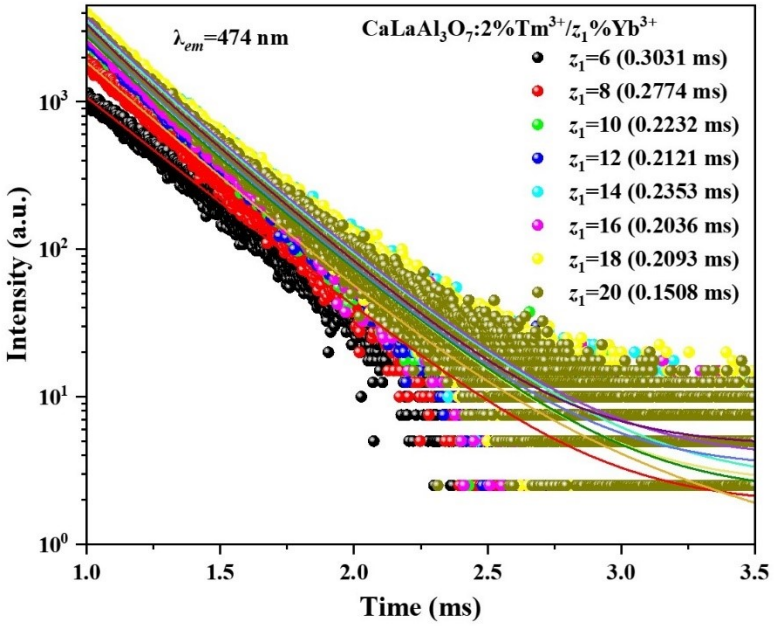

Fig. S12 Upconversion emission decay curves of $CaLaAl_3O_7$:2%Tm^{3+}/z_1%Yb^{3+} (z_1 = 6, 8, 10, 12, 14, 16, 18, 20) phosphors at a monitoring emission wavelength of 474 nm upon 980 nm pulsed excitation.

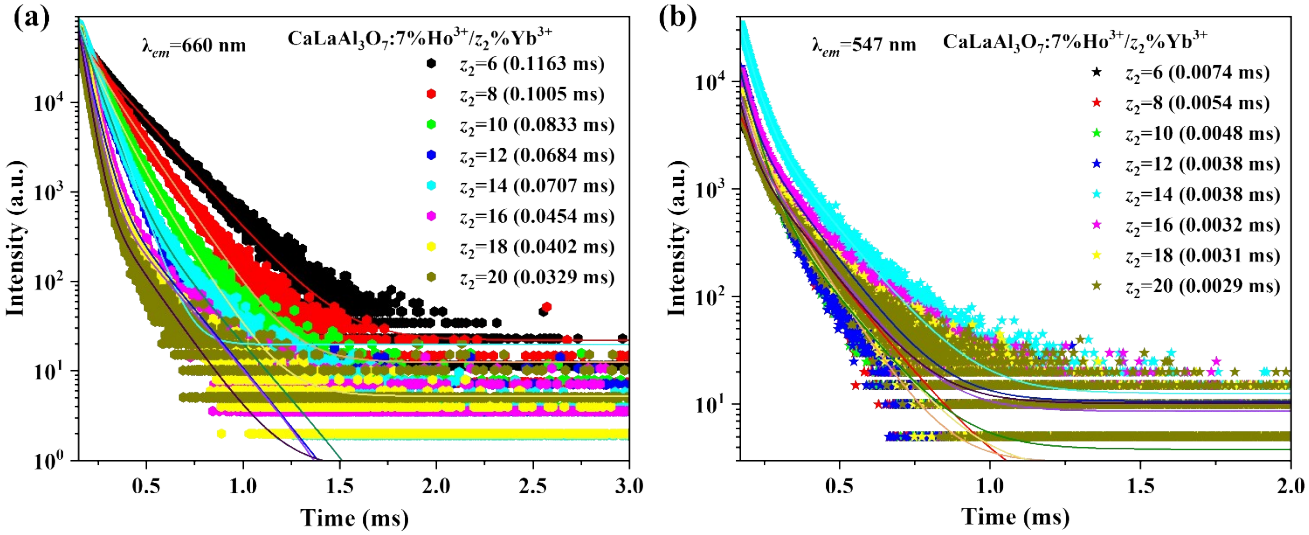

Fig. S13 Upconversion emission decay curves of $CaLaAl_3O_7$:7%Ho^{3+}/z_2%Yb^{3+} (z_2 = 6, 8, 10, 12, 14, 16, 18, 20) phosphors at a monitoring emission wavelength of (a) 660 nm, (b) 547 nm upon 980 nm pulsed excitation.

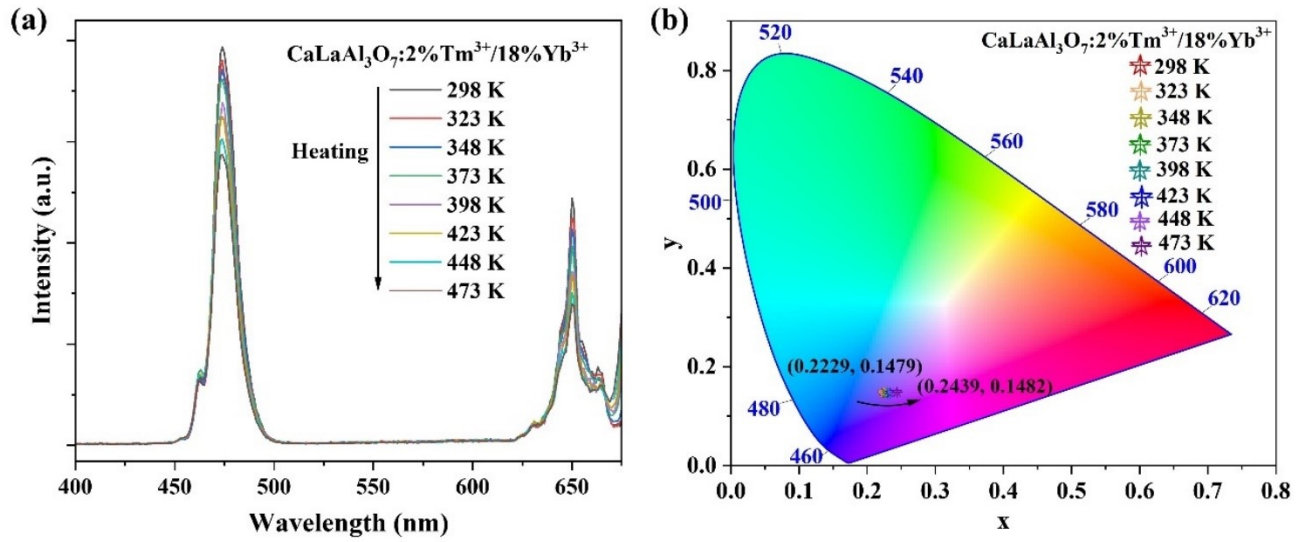

Fig. S14 (a) Thermal stability of $CaLaAl_3O_7$:2%Tm^{3+}/18%Yb^{3+} phosphor between 298-473K, with a testing interval of 25 K **(b)** Changes in chromaticity coordinates of $CaLaAl_3O_7$:2%Tm^{3+}/18%Yb^{3+}phosphor at different temperatures

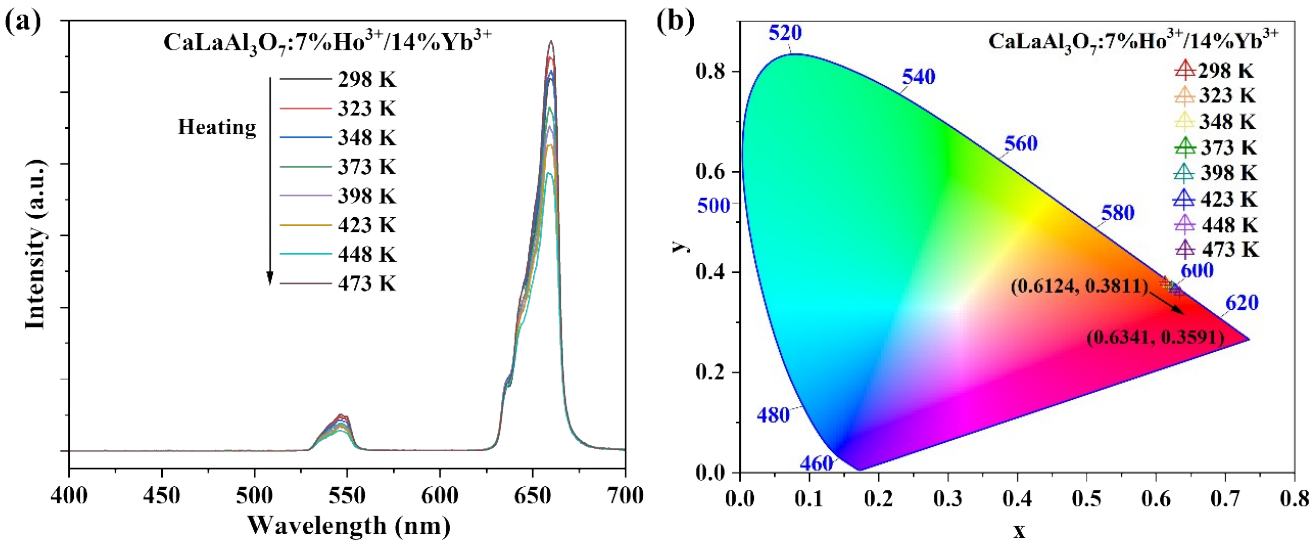

Fig. S15 (a) Thermal stability of $CaLaAl_3O_7$:2%Tm^{3+}/18%Yb^{3+} phosphor between 298-473K, with a testing interval of 25 K **(b)** Changes in chromaticity coordinates of $CaLaAl_3O_7$:7%Ho^{3+}/14%Yb^{3+} phosphor at different temperatures

Table S1 Results of EDS mapping of the $CaLaAl_3O_7$:2%Tm^{3+}/18%Yb^{3+} representative.

Element	wt%	Wt% Sigma	At%
O	38.30	0.43	66.87
Al	20.02	0.38	20.73
Ca	8.72	0.14	6.07
La	25.22	0.34	5.07
Tm	0.93	0.32	0.15
Yb	6.82	0.39	1.10
Total	100.00		100.00

Table S2 Results of EDS mapping of the $CaLaAl_3O_7$:7%Ho^{3+}/14%Yb^{3+} representative.

Element	wt%	Wt% Sigma	At%
O	28.98	0.65	61.65
Al	14.61	0.39	18.42
Ca	10.74	0.30	9.12
La	37.22	0.81	9.12
Ho	2.87	1.02	0.59
Yb	5.57	0.85	1.10
Total	100.00		100.00

Table S3 CIE parameters of $CaLaAl_3O_7$:2%Tm^{3+}/z_1%Yb^{3+} (z_1 = 6, 8, 10, 12, 14, 16, 18, 20) phosphors.

Yb^{3+} Concentration z_1	Excitation wavelength (nm)	CIE coordinate x	y
6	288	0.2803	0.6215
8	288	0.2782	0.6231
10	288	0.2810	0.6206
12	288	0.2818	0.6192
14	288	0.2893	0.6135
16	288	0.2870	0.6143
18	288	0.2845	0.6177
20	288	0.2855	0.6135

Table S4 CIE parameters of $CaLaAl_3O_7$:2%Tm^{3+}/z_1%Yb^{3+} (z_1 = 6, 8, 10, 12, 14, 16, 18, 20) phosphors.

Yb^{3+} Concentration z_1	Excitation wavelength (nm)	CIE coordinate	
		x	y
6	355	0.2891	0.5838
8	355	0.2897	0.5829
10	355	0.2909	0.5832
12	355	0.2875	0.5850
14	355	0.2957	0.5827
16	355	0.2908	0.5847
18	355	0.2894	0.5856
20	355	0.2882	0.5858

Table S5 CIE parameters of $CaLaAl_3O_7$:7%Ho^{3+}/z_2%Yb^{3+} (z_2 = 6, 8, 10, 12, 14, 16, 18, 20) phosphors.

Yb^{3+} Concentration z_2	Excitation wavelength (nm)	CIE coordinate	
		x	y
6	288	0.2926	0.6773
8	288	0.2935	0.6760
10	288	0.2937	0.6751
12	288	0.2933	0.6754
14	288	0.2952	0.6706
16	288	0.2935	0.6738
18	288	0.2934	0.6749
20	288	0.2950	0.6717

Table S6 CIE parameters of $CaLaAl_3O_7$:7%Ho^{3+}/z_2%Yb^{3+} (z_2 = 6, 8, 10, 12, 14, 16, 18, 20) phosphors.

Yb^{3+} Concentration z_2	Excitation wavelength (nm)	CIE coordinate	
		x	y
6	361	0.2827	0.6992
8	361	0.2824	0.6996
10	361	0.2821	0.6997
12	361	0.2822	0.6996
14	361	0.2819	0.6990
16	361	0.2814	0.7005
18	361	0.2816	0.6997
20	361	0.2817	0.6995

Table S7 CIE parameters of $CaLaAl_3O_7$:2%Tm^{3+}/z_1%Yb^{3+} (z_1 = 6, 8, 10, 12, 14, 16, 18, 20) phosphors.

Yb^{3+} Concentration z_1	Excitation wavelength (nm)	CIE coordinate	
		x	y
6	462	0.3404	0.4105
8	462	0.3404	0.4091
10	462	0.3370	0.4145
12	462	0.3394	0.4112
14	462	0.3318	0.4273
16	462	0.3313	0.4269
18	462	0.3354	0.4225
20	462	0.3335	0.4225

Table S8 CIE parameters of $CaLaAl_3O_7$:7%Ho^{3+}/z_2%Yb^{3+} (z_2 = 6, 8, 10, 12, 14, 16, 18, 20) phosphors.

Yb^{3+} Concentration z_2	Excitation wavelength (nm)	CIE coordinate	
		x	y
6	450	0.2756	0.7041
8	450	0.2749	0.7044
10	450	0.2748	0.7041
12	450	0.2745	0.7043
14	450	0.2738	0.7043
16	450	0.2736	0.7054
18	450	0.2730	0.7054
20	450	0.2732	0.7048

Table S9 CIE parameters of $CaLaAl_3O_7$:2%Tm^{3+}/z_1%Yb^{3+} (z_1 = 6, 8, 10, 12, 14, 16, 18, 20) phosphors.

Yb^{3+} Concentration z_1	Excitation wavelength (nm)	CIE coordinate	
		x	y
6	980	0.2272	0.1740
8	980	0.2140	0.1609
10	980	0.2052	0.1528
12	980	0.2072	0.1497
14	980	0.2023	0.1498
16	980	0.2017	0.1493
18	980	0.1993	0.1467
20	980	0.2011	0.1489

Table S10 CIE parameters of $CaLaAl_3O_7$:7%Ho^{3+}/z_2%Yb^{3+} (z_2 = 6, 8, 10, 12, 14, 16, 18, 20) phosphors.

Yb^{3+} Concentration z_2	Excitation wavelength (nm)	CIE coordinate	
		x	y
6	980	0.6131	0.3803
8	980	0.6094	0.3845
10	980	0.6010	0.3931
12	980	0.6017	0.3927
14	980	0.5964	0.3986
16	980	0.5863	0.4083
18	980	0.5779	0.4163
20	980	0.5761	0.4183