

Supporting Information

Full Visible LED Enabled by the Broadband Yellow Emission Nepheline Phosphor Derived from Europium Doped SOD Zeolite

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Table S1. Crystallographic data, structure refinement parameters of Eu²⁺-SOD-x (x = 700, 800, 900, 1000, 1100, 1200, 1300) phosphors.

	Eu ²⁺ -SOD- 700	Eu ²⁺ -SOD- 800	Eu ²⁺ -SOD- 900	Eu ²⁺ -SOD- 1000	Eu ²⁺ -SOD- 1100	Eu ²⁺ -SOD- 1200	Eu ²⁺ -SOD- 1300
Unit cell	a=8.88689 Å	a=8.88689 Å	a=10.01000 Å	a=10.01000 Å	a=10.01000 Å	a=10.01000 Å	a=10.01000 Å
	b=8.88689 Å	b=8.88689 Å	b=10.01000 Å	b=10.01000 Å	b=10.01000 Å	b=10.01000 Å	b=10.01000 Å
	c=8.88689 Å	c=8.88689 Å	c=8.40500 Å	c=8.40500 Å	c=8.40500 Å	c=8.40500 Å	c=8.40500 Å
Cell volume	V=701.858 355 Å ³	V=701.858 355 Å ³	V=729.350 9 Å ³	V=729.350 9 Å ³	V=729.350 9 Å ³	V=729.350 9 Å ³	V=729.350 9 Å ³
Space group	P-43n (218)	P-43n (218)	P-63 (173)	P-63 (173)	P-63 (173)	P-63 (173)	P-63 (173)
R _{exp}	2.47 %	0.47%	12.11%	13.42%	10.14%	14.79%	14.47%
R _{wp}	0.97%	0.29%	6.34%	4.18%	5.36%	0.77%	0.87%
χ ²	0.66	0.43	0.63	1.58	0.34	0.38	0.79

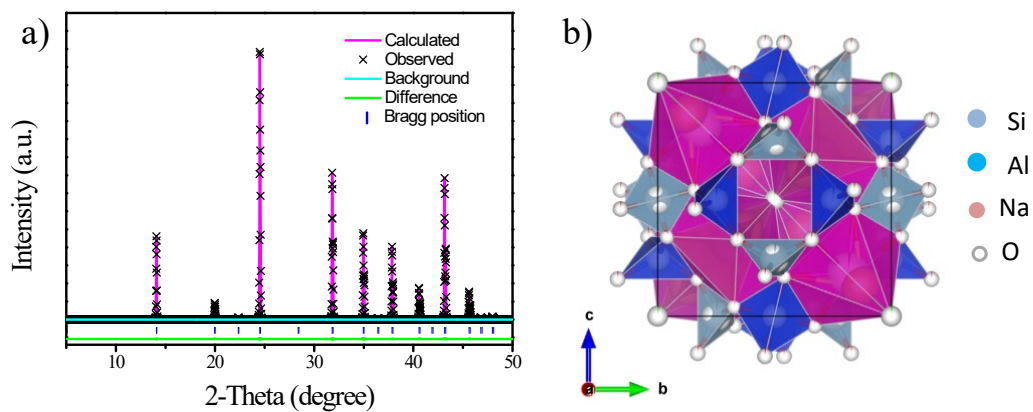


Figure S1. (a) XRD profile for Rietveld refinement of Eu^{2+} -SOD-700 phosphor. (b) Schematic crystal structure of Eu^{2+} -SOD-700 phosphor.

Table S2. Fractional Atomic Coordinates of Eu²⁺-SOD-700 phosphor.

Atom	Site	x	y	Z
Na	8e	-0.574175	-0.574175	-0.574175
Al	6d	0.25000	0.00000	0.50000
Si	6c	0.25000	0.50000	0.00000
O1	24i	0.17163	0.15894	0.45912
O2	2a	0.00000	0.00000	0.00000
Eu	8e	-0.574175	-0.574175	-0.574175

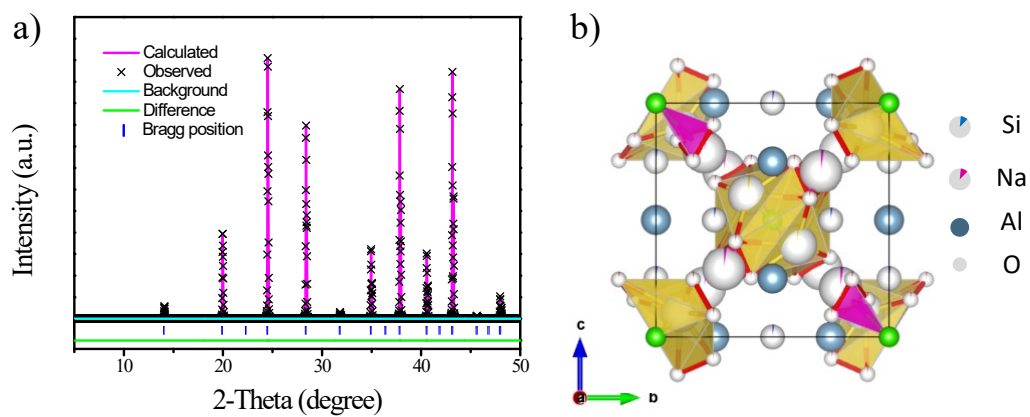


Figure S2. (a) XRD profile for Rietveld refinement of Eu²⁺-SOD-800 phosphor. (b) Schematic crystal structure of Eu²⁺-SOD-800 phosphor.

Table S3. Fractional Atomic Coordinates of Eu²⁺-SOD-800 phosphor.

Atom	Site	x	y	z
Na	8e	2.89449	2.89449	2.89449
Al	6d	0.25000	0.00000	0.50000
Si	6c	0.25000	0.50000	0.00000
O1	24i	-3.34075	2.40743	-8.76585
O2	2a	0.00000	0.00000	0.00000
Eu	8e	2.89449	2.89449	2.89449

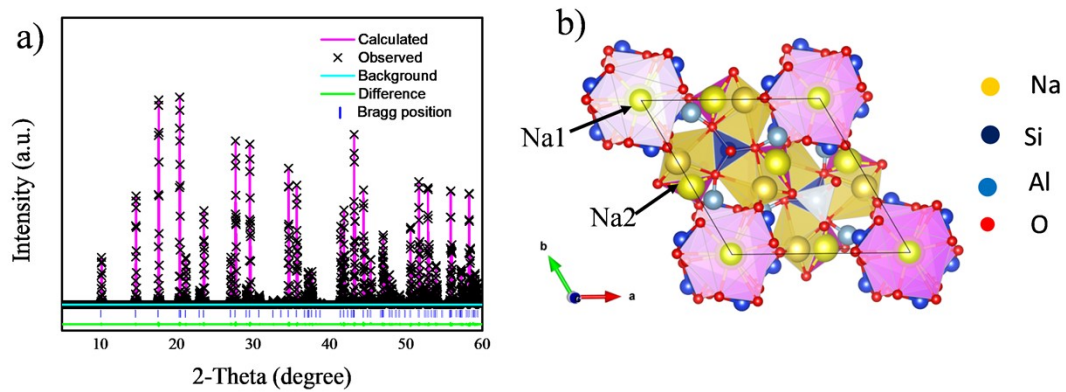


Figure S3. (a) XRD profile for Rietveld refinement of Eu^{2+} -SOD-900 phosphor. (b) Schematic crystal structure of Eu^{2+} -SOD-900 phosphor.

Table S4. Fractional Atomic Coordinates of Eu²⁺-SOD-900 phosphor.

Atom	Type	Site	x	y	z
Na	Na1	2a	0.00000	0.00000	0.33270
Si	Si1	2b	0.33333	0.66667	0.741285
Al	Al1	2b	0.33333	0.66667	0.087217
O	O1	2b	0.33333	0.66667	-0.04479
Na	Na2	6c	0.01099	0.40062	1.28319
Si	Si2	6c	0.09504	0.31803	0.30584
Al	Al2	6c	0.09163	0.34470	0.64655
O	O2	6c	0.00600	0.30632	0.40936
O	O3	6c	0.18513	0.50786	0.66412
O	O4	6c	0.16750	0.54676	0.18804
O	O5	6c	0.22599	0.27103	-0.14787
O	O6	6c	0.20524	0.27305	0.41059
Eu	Eu	6c	0.01099	0.40062	1.28319

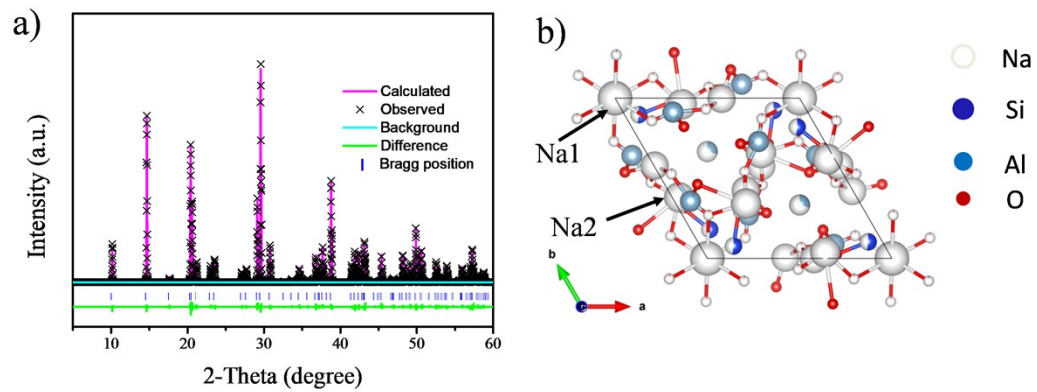


Figure S4. (a) XRD profile for Rietveld refinement of Eu^{2+} -SOD-1000 phosphor. (b) Schematic crystal structure of Eu^{2+} -SOD-1000 phosphor.

Table S5. Fractional Atomic Coordinates of Eu²⁺-SOD-1000 phosphor.

Atom	Type	Site	x	y	z
Na	Na1	2a	0.00000	0.00000	0.13842
Si	Si1	2b	0.33333	0.66667	1.08536
Al	Al1	2b	0.33333	0.66667	0.47727
O	O1	2b	0.33333	0.66667	0.32781
Na	Na2	6c	-0.00464	0.42041	0.05996
Si	Si2	6c	0.10323	0.18036	0.38315
Al	Al2	6c	0.08727	0.35760	0.80284
O	O2	6c	-0.12823	0.14163	0.29797
O	O3	6c	0.17802	0.46241	0.94348
O	O4	6c	9.99999	-9.99999	-1.33891
O	O5	6c	0.02598	0.31234	0.39028
O	O6	6c	0.06884	-0.47316	0.78229
Eu	Eu	6c	-0.00464	0.42041	0.05996

Table S6. Fractional Atomic Coordinates of Eu²⁺-SOD-1100 phosphor.

Atom	Type	Site	x	y	z
Na	Na1	2a	0.00000	0.00000	0.01032
Si	Si1	2b	0.33333	0.66667	0.88484
Al	Al1	2b	0.33333	0.66667	0.34929
O	O1	2b	0.33333	0.66667	0.09292
Na	Na2	6c	-0.00603	0.38997	-0.00717
Si	Si2	6c	0.09142	0.31279	0.32251
Al	Al2	6c	0.07796	0.32447	0.72111
O	O2	6c	0.01390	0.29801	0.55176
O	O3	6c	0.13816	0.44600	0.80512
O	O4	6c	0.20350	0.53587	0.26411
O	O5	6c	0.21529	0.28323	0.01456
O	O6	6c	0.37854	-0.65419	0.45671
Eu	Eu	6c	-0.00603	0.38997	-0.00717

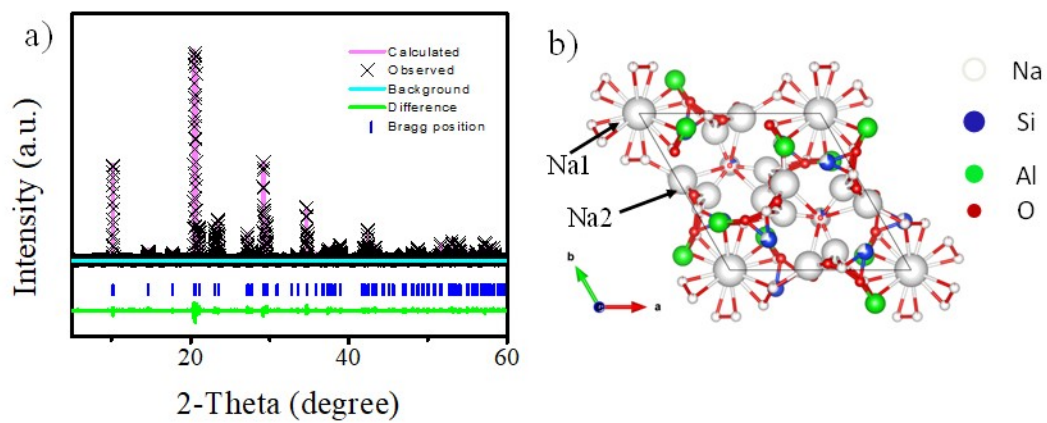


Figure S5. (a) XRD profile for Rietveld refinement of Eu^{2+} -SOD-1200 phosphor. (b) Schematic crystal structure of Eu^{2+} -SOD-1200 phosphor.

Table S7. Fractional Atomic Coordinates of Eu²⁺-SOD-1200 phosphor.

Atom	Type	Site	x	y	z
Na	Na1	2a	0.00000	0.00000	0.10606
Si	Si1	2b	0.33333	0.66667	1.19495
Al	Al1	2b	0.33333	0.66667	0.15194
O	O1	2b	0.33333	0.66667	0.21868
Na	Na2	6c	0.36236	0.88660	-0.78233
Si	Si2	6c	0.11755	0.31169	0.42189
Al	Al2	6c	0.09118	0.30412	0.77021
O	O2	6c	-0.07416	0.24454	0.40135
O	O3	6c	-9.88581	1.29612	0.76587
O	O4	6c	0.04055	0.47933	0.44808
O	O5	6c	0.38976	0.37542	-0.00369
O	O6	6c	0.22449	0.29766	0.63759
Eu	Eu	6c	0.36236	0.88660	-0.78233

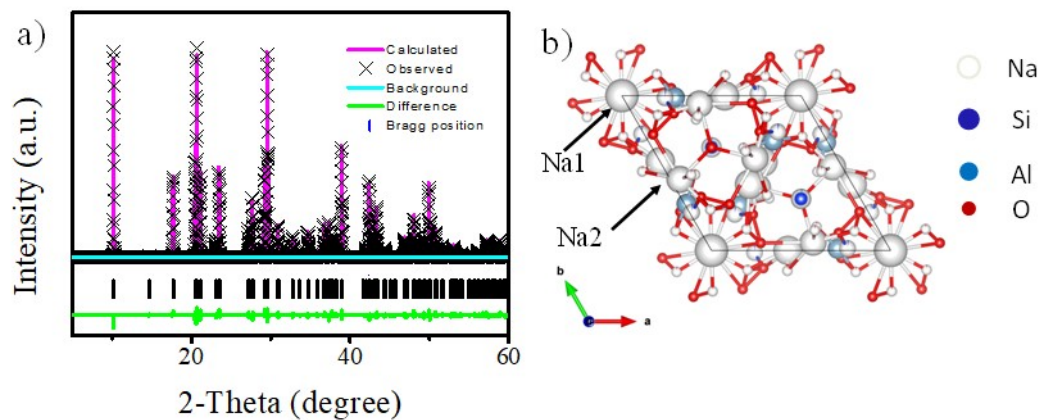


Figure S6. (a) XRD profile for Rietveld refinement of Eu^{2+} -SOD-1300 phosphor. (b) Schematic crystal structure of Eu^{2+} -SOD-1300 phosphor.

Table S8. Fractional Atomic Coordinates of Eu²⁺-SOD-1300 phosphor.

Atom	Type	Site	x	y	z
Na	Na1	2a	0.00000	0.00000	-0.37177
Si	Si1	2b	0.33333	0.66667	1.40375
Al	Al1	2b	0.33333	0.66667	0.38582
O	O1	2b	0.33333	0.66667	0.04909
Na	Na2	6c	0.05375	0.45939	-1.04383
Si	Si2	6c	0.24690	0.23384	0.30793
Al	Al2	6c	0.01159	0.30091	0.65227
O	O2	6c	-0.04862	0.25015	0.47537
O	O3	6c	0.15317	0.49070	0.74674
O	O4	6c	0.13080	0.48913	0.22751
O	O5	6c	0.34623	0.23206	0.44481
O	O6	6c	0.12540	0.26356	1.06565
Eu	Eu	6c	0.05375	0.45939	-1.04383

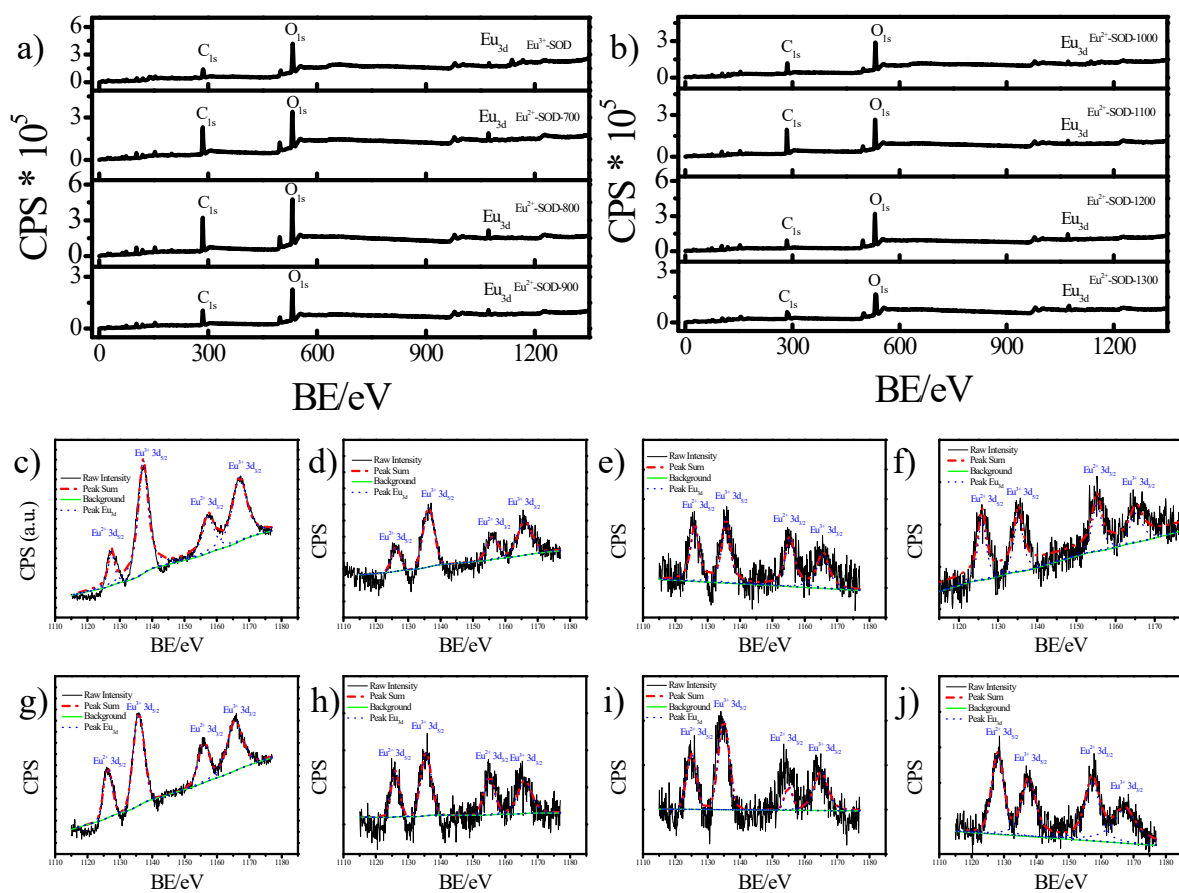


Figure S7. (a,b) XPS survey spectra of Eu³⁺-SOD and Eu²⁺-SOD-x (x = 700, 800, 900, 1000, 1100, 1200, 1300). (c~j) Eu 3d_{5/2} and Eu 3d_{3/2} core level spectra of of Eu³⁺-SOD and Eu²⁺-SOD-x (x = 700, 800, 900, 1000, 1100, 1200, 1300).

Table S9. Peak area analysis of the XPS results.

Phosphors	Relative Peak Area (%)		Eu ²⁺ / Eu ³⁺
	Eu ²⁺	Eu ³⁺	
Eu ³⁺ -SOD	40.98	59.12	0.69
Eu ²⁺ -SOD-700	45.97	54.03	0.86
Eu ²⁺ -SOD-800	44.70	55.30	0.81
Eu ²⁺ -SOD-900	48.78	51.22	0.95
Eu ²⁺ -SOD-1000	59.50	40.50	1.47
Eu ²⁺ -SOD-1100	47.63	52.37	0.91
Eu ²⁺ -SOD-1200	51.28	48.72	1.05
Eu ²⁺ -SOD-1300	54.73	45.27	1.21

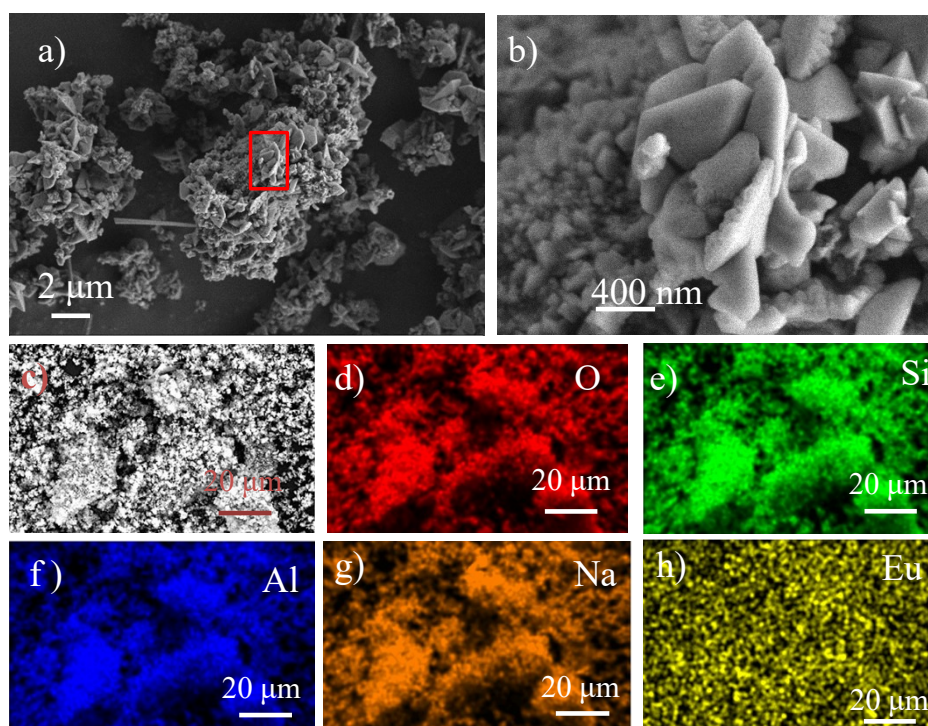


Figure S8. (a) (c) SEM images of Eu³⁺-SOD microcrystal particles and (b) an enlarged particle. (d ~ h) Element mapping images of O, Si, Al, Na, and Eu for the Eu³⁺-SOD particles.

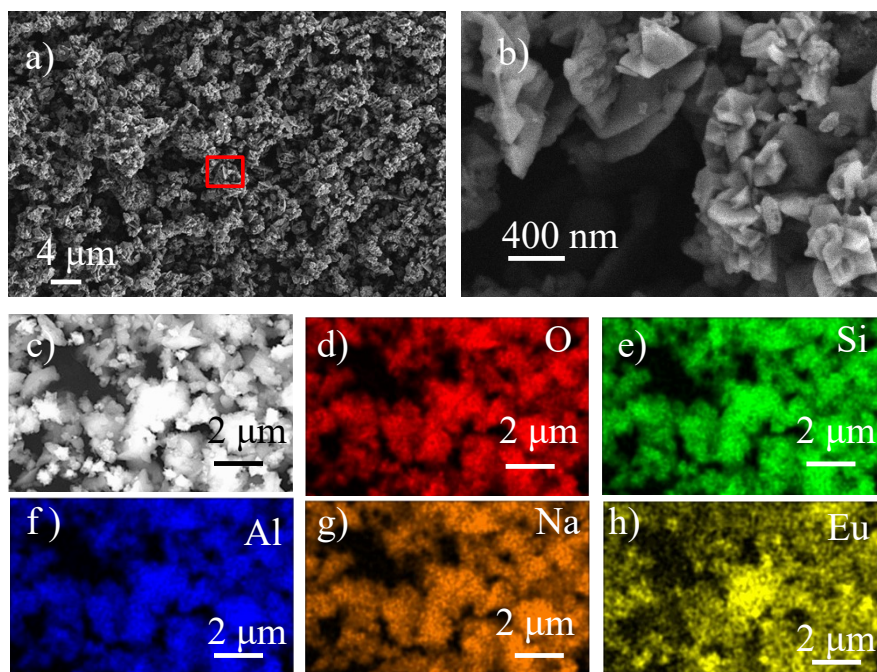


Figure S9. (a) (c) SEM images of Eu^{2+} -SOD-700 microcrystal particles and (b) an enlarged particle. (d ~ h) Element mapping images of O, Si, Al, Na, and Eu for the Eu^{2+} -SOD-700 particles.

Table S10. Elemental analysis on the Eu²⁺-SOD-700 phosphors.

Atom	Weight %	Atomic %	Error %
O/K	47.32	64.09	8.27
Na/K	10.00	9.43	1.01
Al/K	16.61	13.34	1.21
Si/K	14.98	11.56	0.99
Eu/L	11.08	1.58	0.54

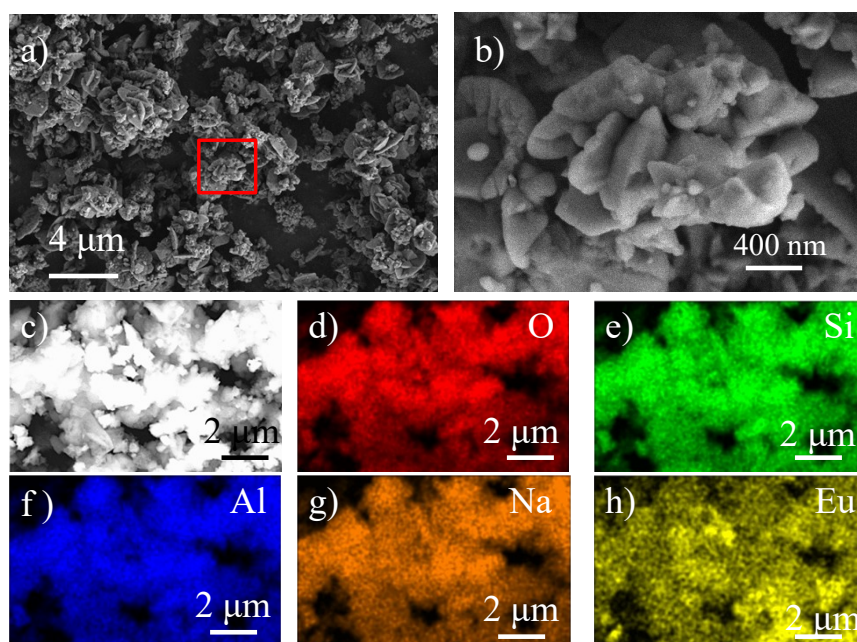


Figure S10. (a) (c) SEM images of Eu²⁺-SOD-800 microcrystal particles and (b) an enlarged particle. (d ~ h) Element mapping images of O, Si, Al, Na, and Eu for the Eu²⁺-SOD-800 particles.

Table S11. Elemental analysis on the Eu²⁺-SOD-800 phosphors.

Atom	Weight %	Atomic %	Error %
O/K	43.73	59.43	13.10
Na/K	13.80	13.05	2.29
Al/K	17.66	14.23	2.17
Si/K	15.43	11.95	1.71
Eu/L	9.37	1.34	0.76

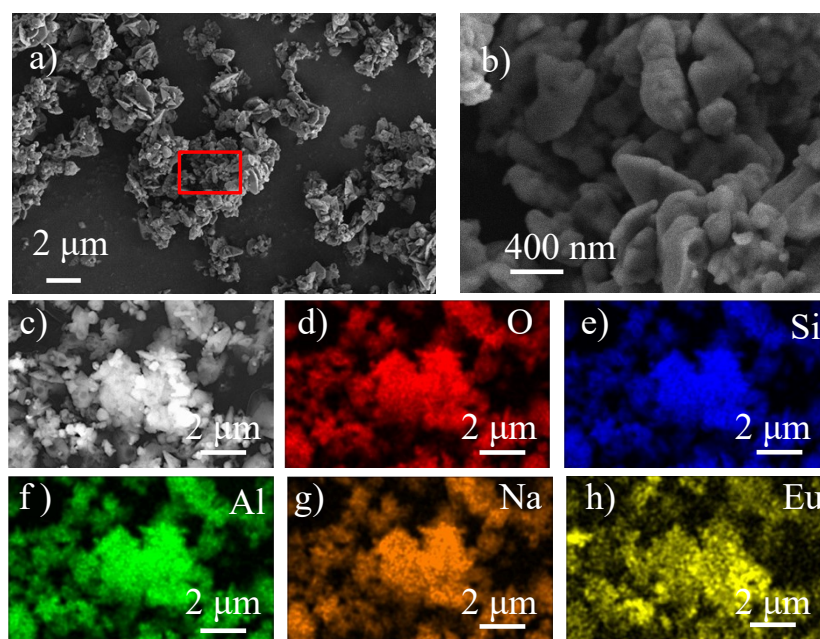


Figure S11. (a) (c) SEM images of Eu²⁺-SOD-900 microcrystal particles and (b) an enlarged particle. (d ~ h) Element mapping images of O, Si, Al, Na, and Eu for the Eu²⁺-SOD-900 particles.

Table S12. Elemental analysis on the Eu²⁺-SOD-900 phosphors.

Atom	Weight %	Atomic %	Error %
O/K	42.06	62.76	15.27
Na/K	6.41	6.65	1.34
Al/K	17.07	15.10	2.53
Si/K	14.53	12.35	1.94
Eu/L	19.94	3.13	1.72

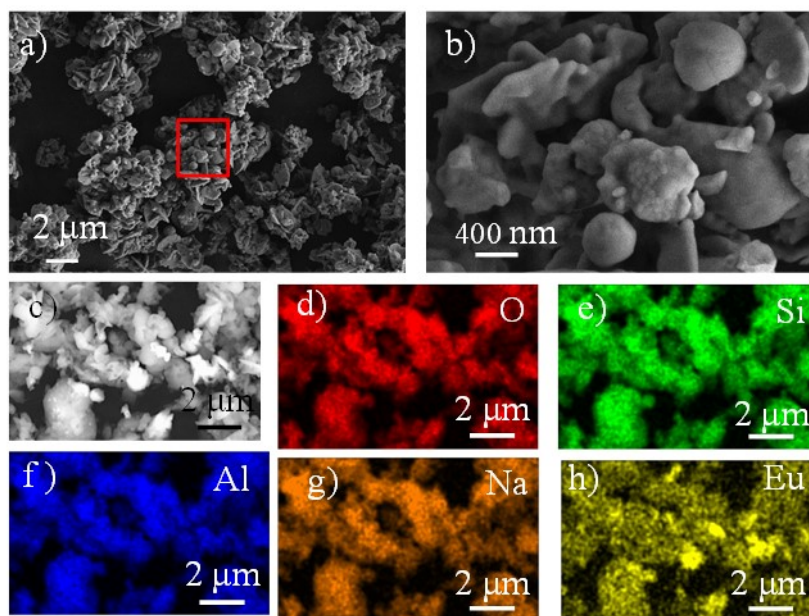


Figure S12. (a) (c) SEM images of Eu^{2+} -SOD-1000 microcrystal particles and (b) an enlarged particle. (d ~ h) Element mapping images of O, Si, Al, Na, and Eu for the Eu^{2+} -SOD-1000 particles.

Table S13. Elemental analysis on the Eu²⁺-SOD-1000 phosphors.

Atom	Weight %	Atomic %	Error %
O/K	36.73	56.37	121.82
Na/K	8.75	9.35	1.69
Al/K	18.66	16.98	2.61
Si/K	16.15	14.12	2.04
Eu/L	18.51	3.18	1.62

Table S14. Elemental analysis on the Eu²⁺-SOD-1100 phosphors.

Atom	Weight %	Atomic %	Error %
O/K	44.58	63.63	17.33
Na/K	8.26	8.20	1.82
Al/K	16.56	14.01	2.65
Si/K	14.41	11.72	2.08
Eu/L	16.19	2.43	1.55

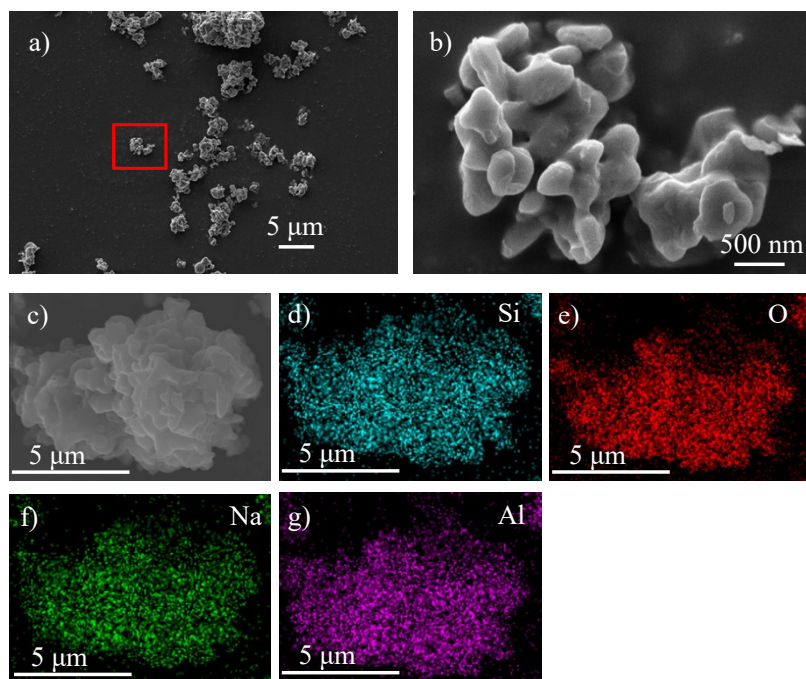


Figure S13. (a) (c) SEM images of Eu^{2+} -SOD-1200 microcrystal particles and (b) an enlarged particle. (d ~ g) Element mapping images of O, Si, Al and Na for the Eu^{2+} -SOD-1200 particles.

Table S15. Elemental analysis on the Eu²⁺-SOD-1200 phosphors.

Atom	Weight %	Atomic %
O/K	49.75	61.80
Na/K	13.64	11.79
Al/K	17.36	12.79
Si/K	19.25	13.62

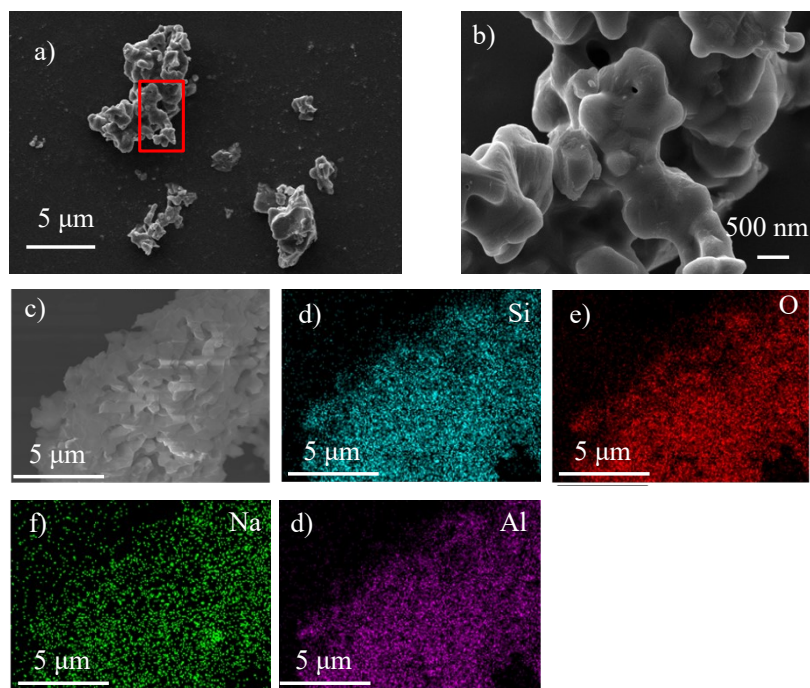


Figure S14. (a) (c) SEM images of Eu^{2+} -SOD-1300 microcrystal particles and (b) an enlarged particle. (d ~ g) Element mapping images of O, Si, Al and Na for the Eu^{2+} -SOD-1300 particles.

Table S16. The decay time and χ^2 of Eu-SOD-x (x = 700, 800, 900, 1000, 1100, 1200 and 1300) phosphors.

Phosphor	Deacy time (μs)	χ^2
SOD-Eu ²⁺ -700	2.38	0.993
SOD-Eu ²⁺ -800	2.37	0.992
SOD-Eu ²⁺ -900	3.00	0.997
SOD-Eu ²⁺ -1000	3.38	0.998
SOD-Eu ²⁺ -1100	3.47	0.996
SOD-Eu ²⁺ -1200	3.38	0.994
SOD-Eu ²⁺ -1300	3.27	0.993

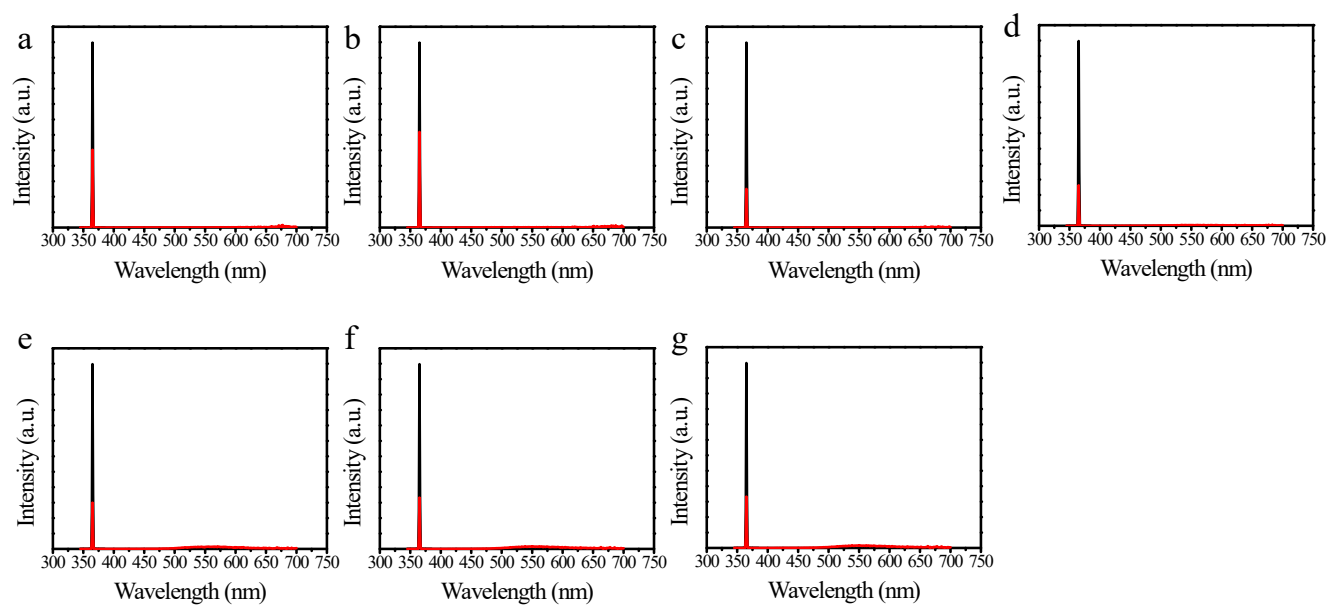


Figure S15. PLQY spectra of Eu^{2+} -SOD-x ((a)x = 700, (b) x = 800, (c) x = 900, (d) x = 1000, (e) x = 1100, (f) x = 1200, (g) x = 1300) phosphors .

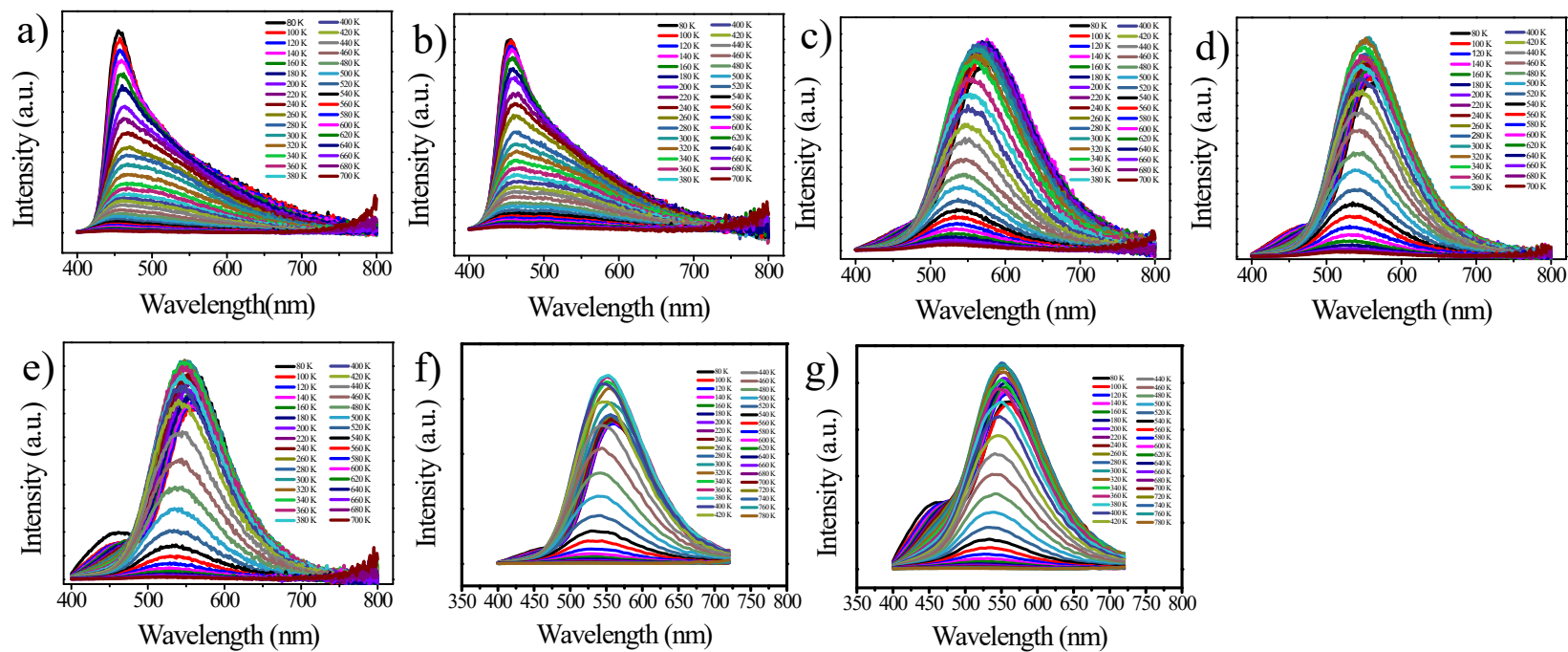


Figure S16. Temperature-dependent emission intensity of Eu^{2+} -SOD- x ((a) $x = 700$, (b) $x = 800$, (c) $x = 900$, (d) $x = 1000$, (e) $x = 1100$, (f) $x = 1200$, (g) $x = 1300$) phosphors measured from 80 to 780 K using 360 nm excitation.