

Electronic Supplementary Information

Highly efficient green-emitting phosphor $\text{Sr}_4\text{Al}_4\text{O}_{25}:\text{Ce},\text{Tb}$ with low thermal quenching and wide color gamut upon UV-light excitation for backlighting display applications

Haoran Li^a, Yujun Liang^{a,*}, Shiqi Liu^a, Weilun Zhang^a, Yanying Bi^a, Yuming Gong^a, Yongjun Chen^b,
Wen Lei^{a,c,*}

^aEngineering Research Center of Nano-Geomaterials of Ministry of Education, Faculty of Materials Science and Chemistry, China University of Geosciences, Wuhan 430074, China. *E-mail:* yujunliang@sohu.com

^bState Key Laboratory of Marine Resource Utilization in South China Sea, School of Materials Science and Engineering, Hainan University, Haikou 570228, China

^cSchool of Electrical, Electronic and Computer Engineering, The University of Western Australia, 35 Stirling Highway Crawley, WA 6009, Australia. *E-mail:* wen.lei@uwa.edu.au

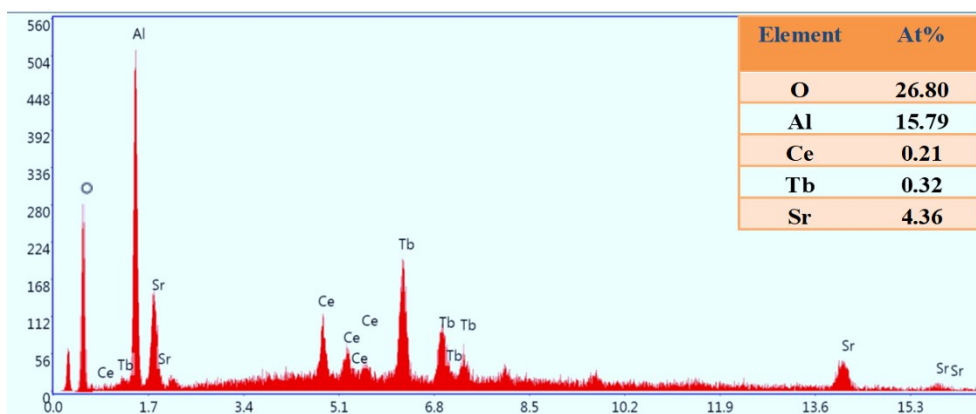


Figure S1. EDS spectrum of Ce, Tb, Sr, O and Al for the selected SAO:0.12Ce³⁺,0.20Tb³⁺ particle.

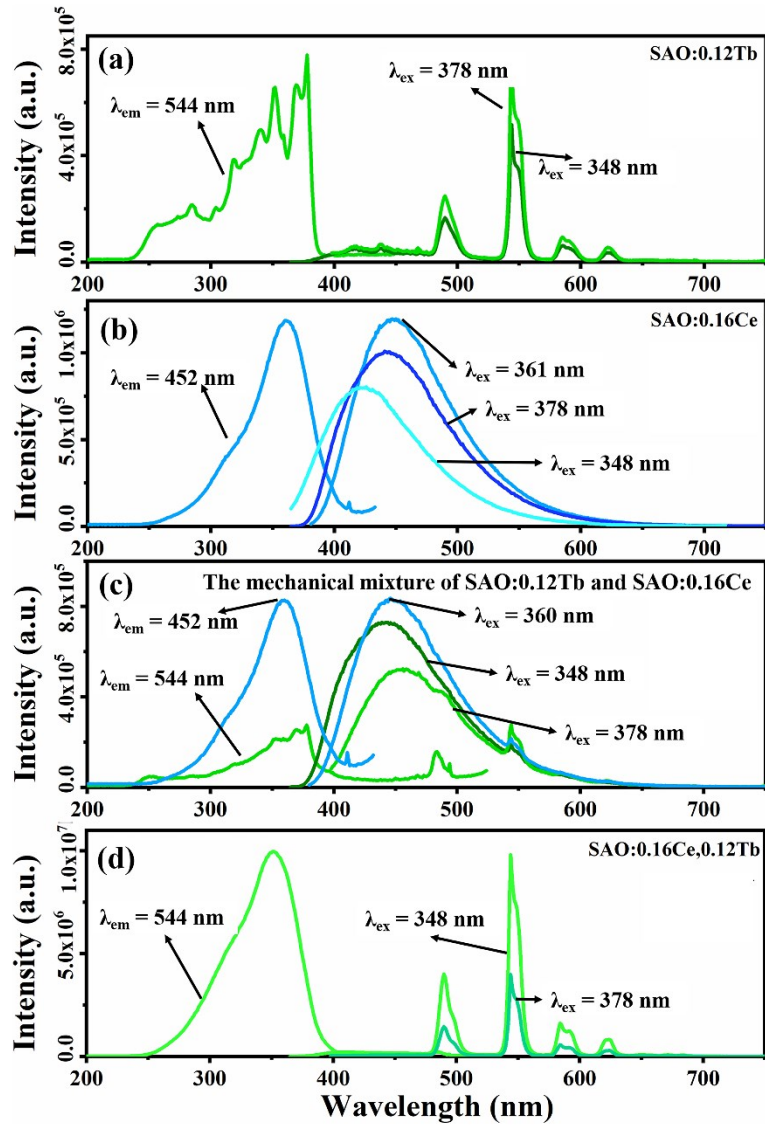


Figure S2. (a) The PLE spectrum monitoring at 544 nm and PL spectra under 348 nm and 378 nm of the selected SAO:0.12Tb³⁺ sample. (b) The PLE spectrum monitoring at 452 nm and PL spectra under 361 nm, 348 nm and 378 nm of SAO:0.16Ce³⁺ sample. (c) The PLE spectra monitoring at 452 nm and 544 nm and PL spectra under 360 nm, 348 nm and 378 nm of the mechanical mixture of SAO:0.16Ce³⁺ and SAO: 0.12Tb³⁺ samples. (d) The PLE spectrum monitoring at 544 nm and PL spectra under 348 nm and 378 nm of SAO:0.16Ce³⁺,0.12Tb³⁺ sample.

The explanation for the overlap between the PL of SAOC and the PLE of SAOT is so small but the ET process takes place indeed:

Generally, the mechanism of energy transfer can be roughly divided into the following three types for the trivalent rare earth ions as the separation luminescence centers in a host.^{S1,S2} They are **(1)** exciton transmission, **(2)** radiation reabsorption, and **(3)** resonance energy transfer. **(1)**: During exciton transmission, the concentration of sensitizer is often lower than that of the activator, while the

concentration of Ce^{3+} is almost 2 times higher than that of Tb^{3+} in the optimal sample. And the emergence of characteristic spectra for excitons is inevitable when excitons generates. Thus, the exciton transmission mode is excluded. **(2):** For the radiation reabsorption, energy is transmitted by photons, which is independent of the distance. And transport process is free from the influence of temperature. The photoluminescence properties for mechanical mixture of Ce^{3+} or Tb^{3+} singly-doped sample should be comparable to that of Ce^{3+} - Tb^{3+} co-doped one. The confirmatory experiment is operated. PLE and PL spectra of SAO:0.16Ce, SAO:0.12Tb, the mixture of SAO:0.16Ce and SAO:0.12Tb samples, and SAO:0.16Ce,0.12Tb powder were measured and the results are shown in Figure S2. It can be seen that the luminescence properties of the two are quite different, indicating the efficiency of energy transfer is closely related to the distance between Ce^{3+} and Tb^{3+} . So, the radiation reabsorption mode is excluded as well. **(3):** A scant overlap between the excitation band of Tb^{3+} and the emission band of Ce^{3+} means the energy transition between the activator and sensitizer might not be in very high probability but remains possible. On the one hand, the overlap between excitation band of activator and emission band of sensitizer is not the only criterion. As shown in Figure S2 a and b, the emission intensity of SAO:0.16Ce³⁺ is twice that of SAO:0.12Tb³⁺. The higher energy of sensitizer (Ce^{3+}) can be absorbed and utilized by the activator (Tb^{3+}) with lower energy in a phosphor so that the SAO:Ce³⁺,Tb³⁺ can absorb more n-UV light and emit stronger green light with main peak at 544 nm. What's more, the emission intensity from Ce^{3+} declines gradually and almost disappears while the emission intensity of peak at 544nm belonging to Tb^{3+} increases dramatically and the average lifetime of Ce reduces significantly by 83% from 13.39 ms to 2.30 ms in SAO:Ce³⁺,Tb³⁺, which illustrates the occurrence of energy transfer from Ce^{3+} to Tb^{3+} .

[S1]. W. M. Yen, S. Shigeo, Y. Hajime, Phosphor Handbook, 2nd ed., New York: CRC Press, 2006.

[S2]. W. M. Yen, M. J. Weber. Inorganic Phosphors, New York: CRC Press, 2004.

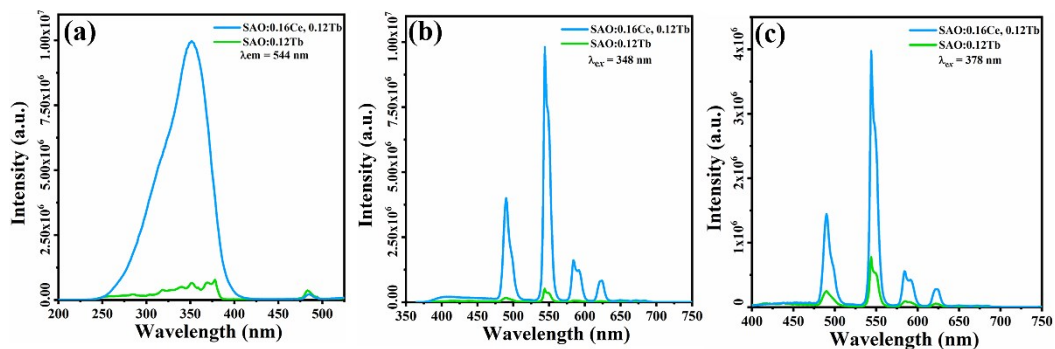


Figure S3. The comparison of (a) PLE spectra monitoring at 544 nm and PL spectra under (b) 348 nm and (c) 378 nm of the selected SAO:0.16Ce³⁺,0.12Tb³⁺ and SAO: 0.12Tb³⁺ samples.

Table S1 Ionic radius of cations in the SAO: Ce³⁺, Tb³⁺.

Ions	Sr ²⁺		Ce ³⁺		Tb ³⁺		Al ³⁺	
	CN [#]	7	8	7	8	7	8	6
R (Å)	1.21	1.26	1.07	1.143	0.98	1.04	0.535	0.39

[#]CN and R represent coordination number and ion radius, respectively.

Table S2 The cell parameters, reliable factors and bond length in SAO:0.16Ce³⁺,0.08Tb³⁺ phosphor.

	a	b	c	V	R _p	R _{wp}	χ ²		
	24.7718 Å	8.4801 Å	4.8848 Å	1026.125Å ³	10.7	5.1	9.3		
Bond length	Sr1-O	Sr2-O	Al1-O	Al2-O	Al3-O	Al4-O	Al5-O	Al6-O	
	2.834 Å	2.597 Å	1.725	1.751	1.796	1.887	1.984	1.974	

Table S3 The coordinates of atoms in SAO:0.16Ce³⁺,0.08Tb³⁺.

Name	x	y	z
Sr1	0.1384	0.5000	0.0325
Sr2	0.1213	0.0000	0.1147
Al1	0.1865	0.1960	0.6381
Al2	0.0662	0.3229	0.6381
Al3	0.2500	0.2920	0.6381
Al4	0.0000	0.1624	0.6381
Al5	0.0000	0.0000	0.6381
Al6	0.0000	0.5000	0.6381
O1	0.0435	0.1708	0.6381
O2	0.1384	0.3131	0.6382
O3	0.1880	0.2224	0.6382
O4	0.2500	0.2372	0.6382
O5	0.0384	0.0000	0.6382
O6	0.0480	0.5000	0.6382
O7	0.1616	0.0000	0.6382
O8	0.0424	0.3348	0.6382
O9	0.2500	0.5000	0.6382