Supplementary Information for

Revisit the SrAl$_2$O$_4$:Eu^{2+},Nd^{3+} persistent phosphor

Rola Kuban†, Yafei Chen†* and Zhengwei Pan[1]*

Center for Integrative Petroleum Research, College of Petroleum Engineering and Geosciences, King Fahd University of Petroleum and Minerals, Dhahran 31261, Saudi Arabia

*Email: panz@uga.edu, yafei.chen@kfupm.edu.sa

†These authors contributed equally to this work

Brief summary − This file contains: X-ray diffraction patterns of SAO:Eu,Nd; PersL decay curves of SAO:Eu,Nd; green and NIR PersL imaging; green and NIR PersL intensities of SAO:Eu,Nd; excitation efficacy of 450 nm LED with varying output intensities; PersL excitation spectrum of SrAl$_2$O$_4$:Eu^{2+},Dy^{3+}; TL spectra of SAO:Eu,Nd; PL excitation spectra of SAO:Eu,Nd at RT and LNT; and PL excitation and emission spectra of SrAl$_2$O$_4$ host.
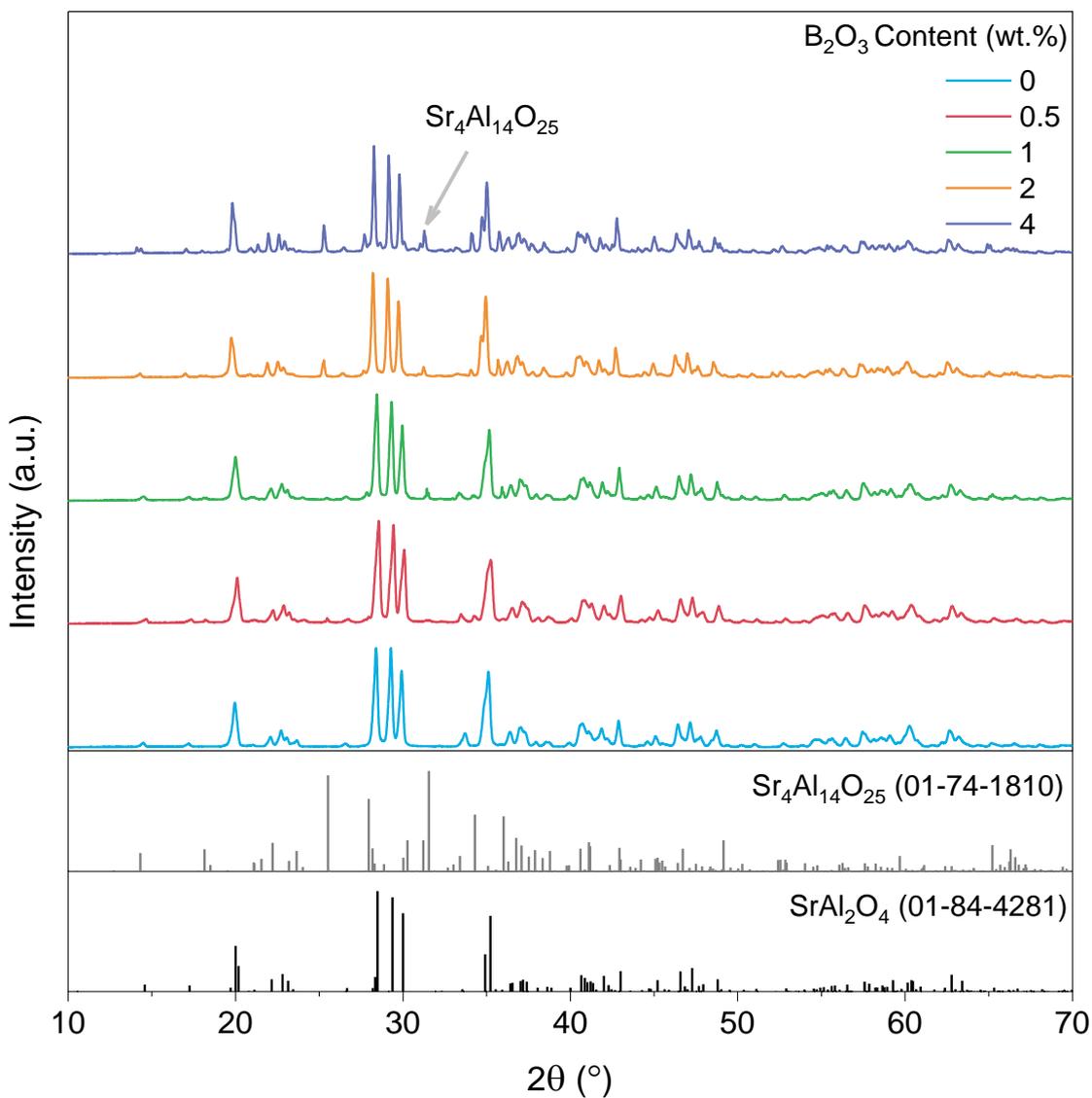
Figure S1 X-ray diffraction patterns of $SrAl_2O_5:0.5\%Eu^{2+},2\%Nd^{3+}$ phosphors with varying B_2O_3 contents (0–4 wt.%). The indexation of monoclinic $SrAl_2O_4$ (ICDD #01-84-4281) and orthorhombic $Sr_4Al_{14}O_{25}$ (ICDD #01-74-1810) are also presented. As the B_2O_3 content increases, $Sr_4Al_{14}O_{25}$ phase appears.
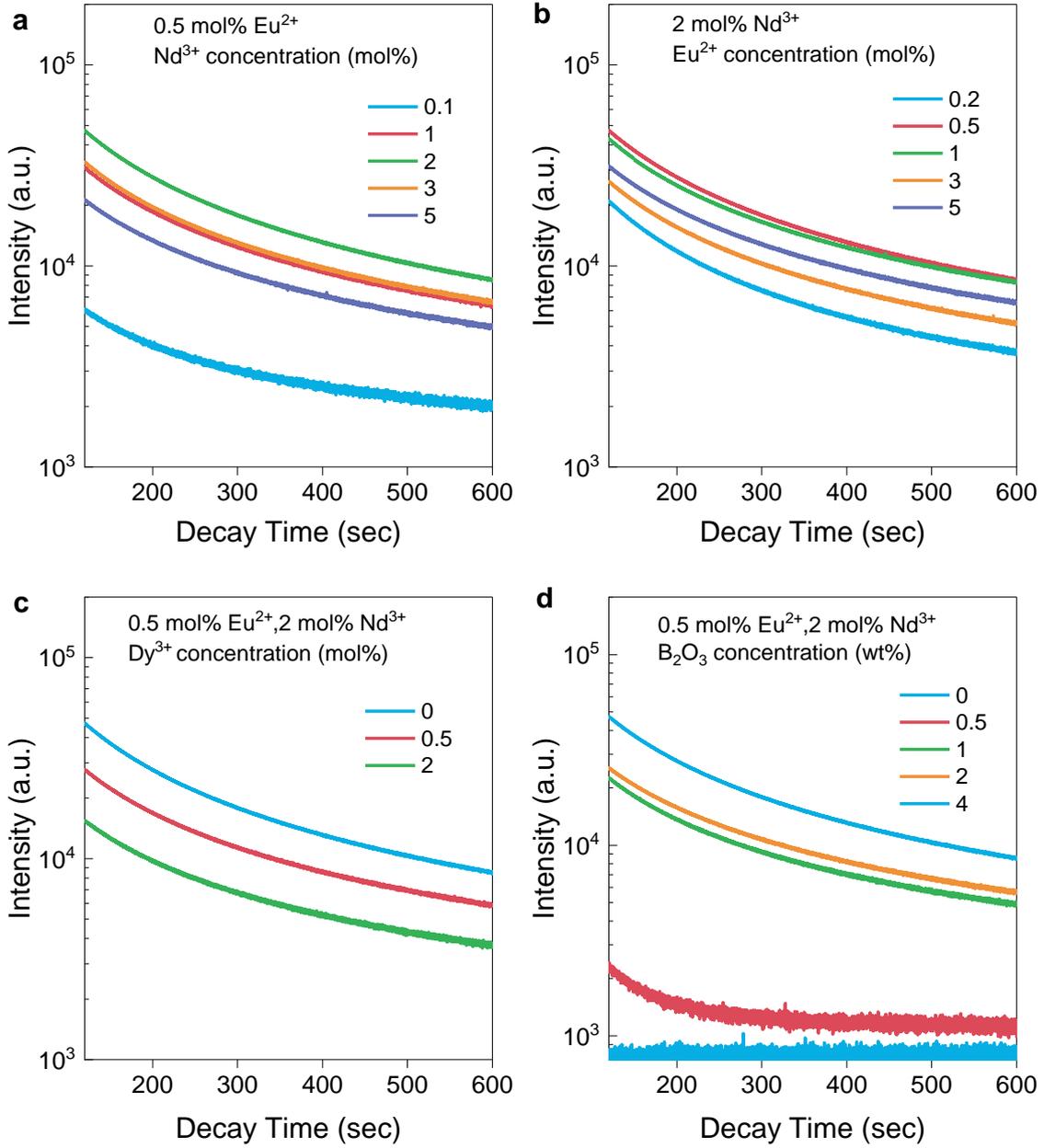
Figure S2 Determination of optimal Eu^{2+}, Nd^{3+}, Dy^{3+}, and B_2O_3 contents in $SrAl_2O_4$:Eu^{2+},Nd^{3+} persistent phosphors according to the PersL decay of Nd^{3+}. (a) Phosphors with 0.5 mol% Eu^{2+} and 0.1–5 mol% Nd^{3+}. (b) Phosphors with 2 mol% Nd^{3+} and 0.2–5 mol% Eu^{2+}. (c) Phosphors with 0.5 mol% Eu^{2+}, 2 mol% Nd^{3+}, and 0–2 mol% Dy^{3+}. (d) Phosphors with 0.5 mol% Eu^{2+}, 2 mol% Nd^{3+}, and 0–4 wt.% B_2O_3. The samples were charged by a white LED flashlight for 1 min. The PersL decay curves were acquired by monitoring the 1060 nm emission of Nd^{3+}.
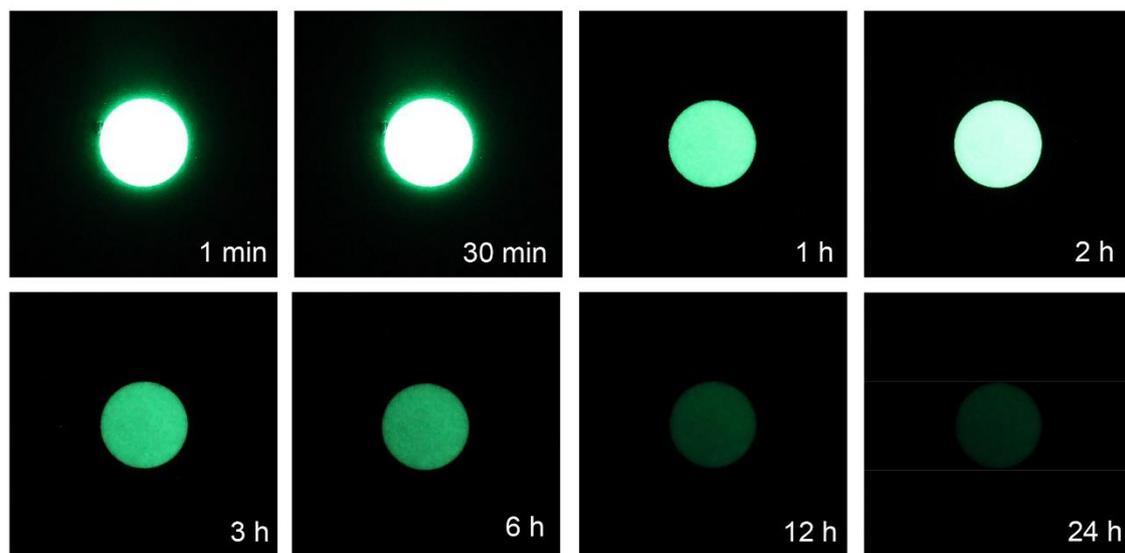
Figure S3 Green PersL images of a SAO:Eu,Nd persistent phosphor disc taken at different decay points (1 min to 24 h) after illumination with a white LED flashlight for 1 min using a Canon digital camera. The imaging parameter was manual/ISO 400/3 s.
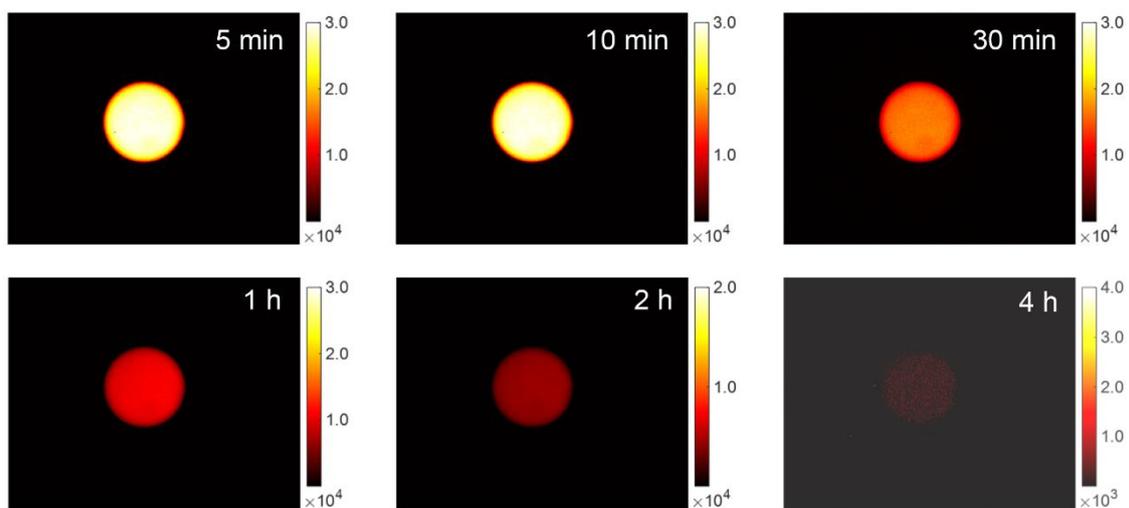
Figure S4 NIR PersL images of a SAO:Eu,Nd persistent phosphor disc taken at different decay points (5 min to 4 h) after irradiated by a white LED flashlight for 1 min using a Teledyne Princeton Instruments NIRvana 640 InGaAs array camera. The exposure time was 30 s.
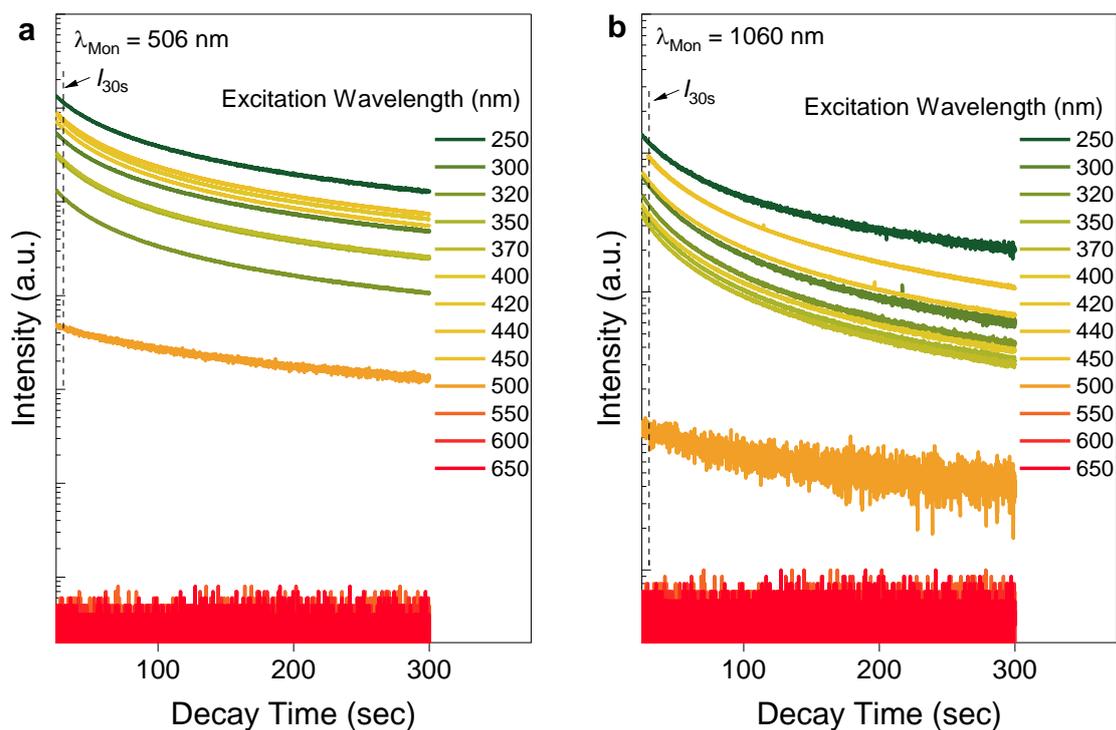
Figure S5 Acquiring PersL excitation spectra of Eu^{2+} and Nd^{3+} in SAO:Eu,Nd persistent phosphor. (a) PersL decay curves by monitoring the 506 nm emission of Eu^{2+}. (b) PersL decay curves by monitoring the 1060 nm emission of Nd^{3+}. The sample was irradiated by monochromatic xenon light between 250–650 nm for 5 min in 10 nm steps. The PersL intensity at time of 30 s after the stoppage of the irradiation (I_{30s}) was used to plot the PersL excitation spectra of Eu^{2+} and Nd^{3+} shown in Fig. 3a and Fig. 3b of the main text, respectively.
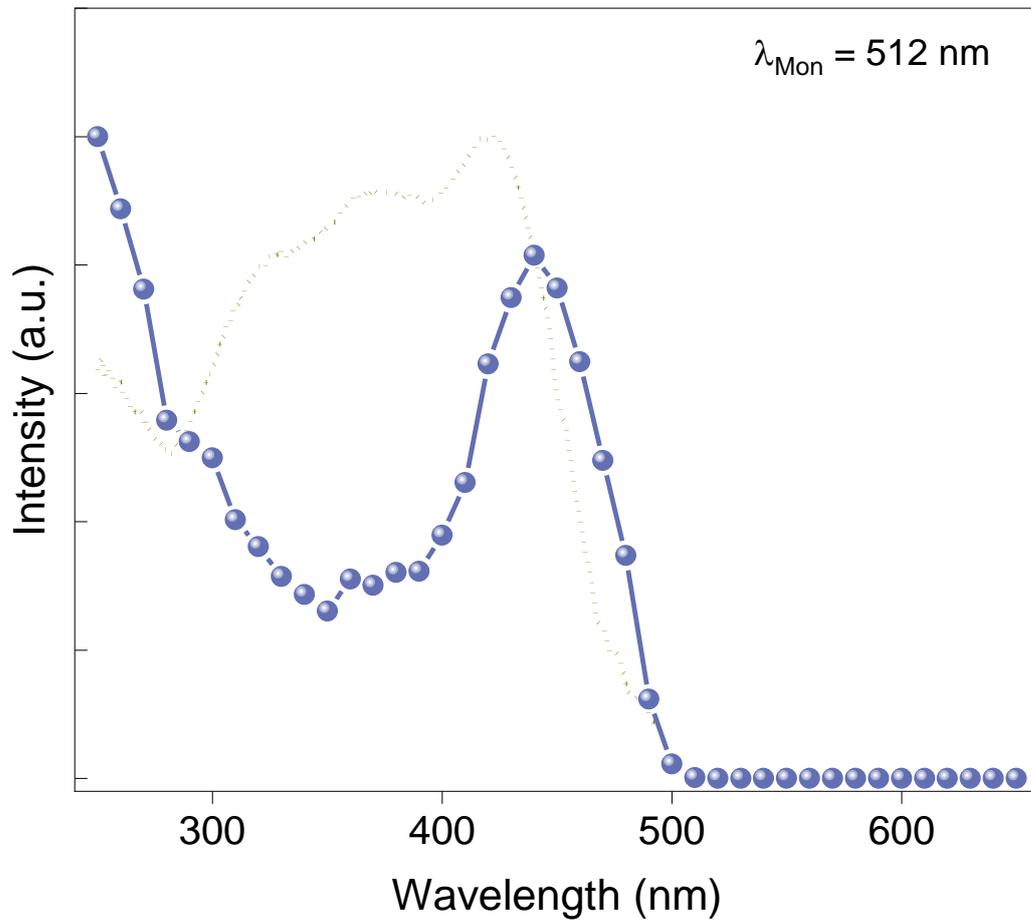
Figure S6 PersL excitation spectrum of $SrAl_2O_4{:}0.5\%Eu^{2+},2\%Dy^{3+}$ persistent phosphor. The method is the same as that used to obtain the PersL excitation spectra of SAO;Eu,Nd phosphor shown in Fig. 3 of the main text. The monitoring wavelength is 512 nm. The grey dot-line curve is the PL excitation spectrum of $SrAl_2O_4{:}0.5\%Eu^{2+},2\%Dy^{3+}$ phosphor by monitoring the 512 nm emission.
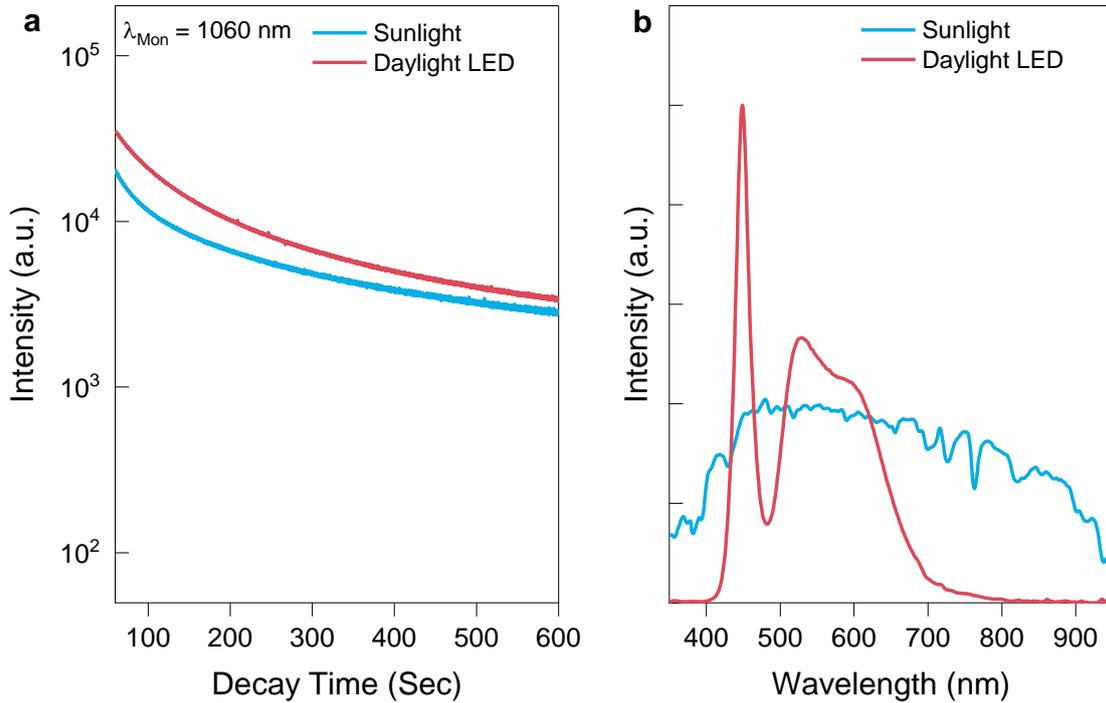
Figure S7 Excitation of a SAO:Eu,Nd phosphor disc using natural sunlight and a Philips 9.5-W daylight LED bulb (6500 K, 1055 lm). (a) PersL decay curves recorded by monitoring the 1060 nm emission of Nd^{3+}. The charging durations were both 5 min. The LED bulb was placed 10 cm above the sample. (b) Normalized emission spectra of natural sunlight and the daylight LED bulb. The spectra were measured using a LISUN LMS-6000S portable CCD spectroradiometer. In measuring the solar spectrum, the detector faced the Sun. In measuring the LED spectrum, the detector was placed towards the bulb at 10 cm distance.
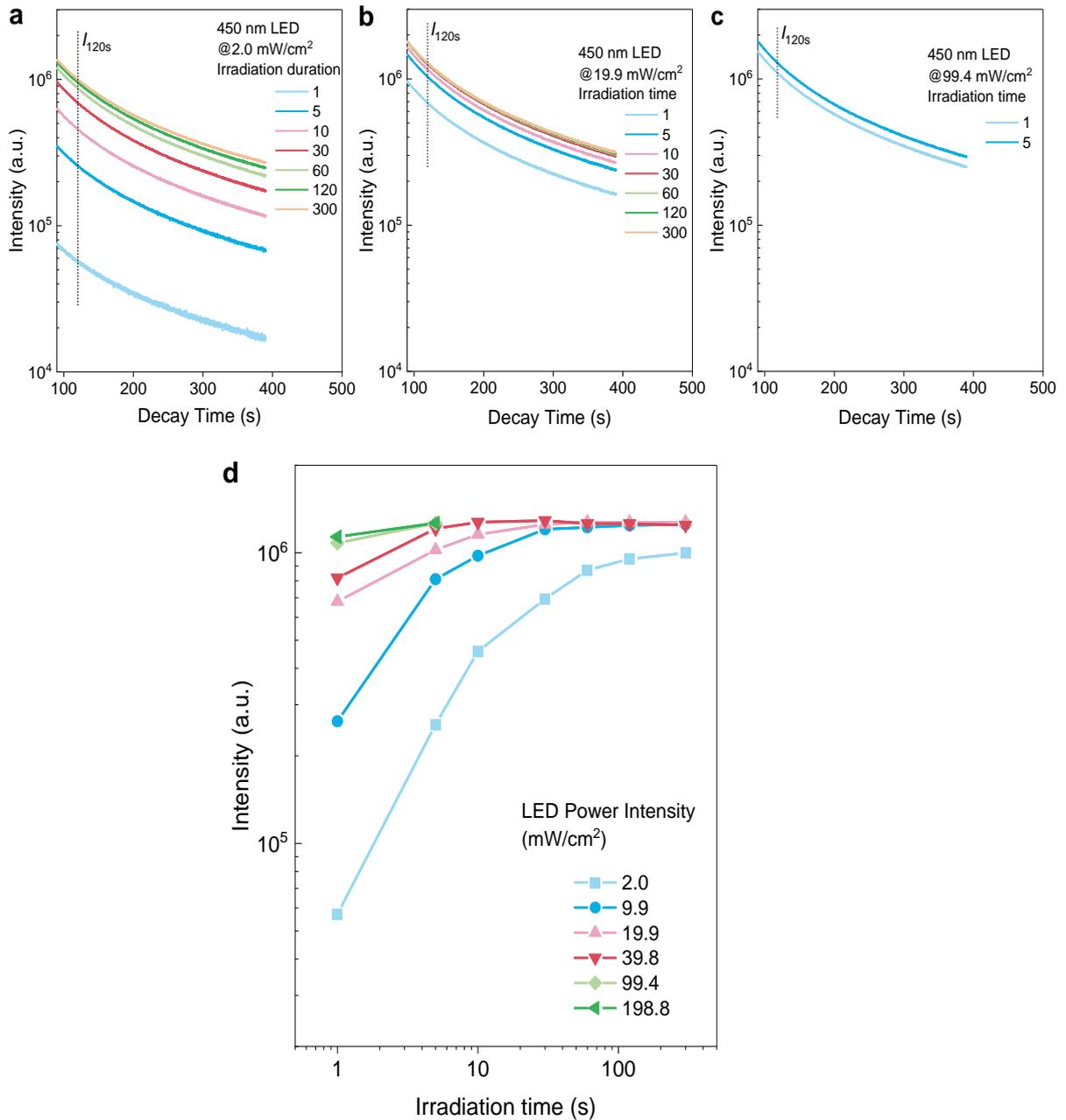
Figure S8 Charging a SAO:Eu,Nd persistent phosphor disc using a power-tunable 450 nm LED at output intensities of 2–200 mW/cm^2 for 1 s to up to 300 s. Before each charging, the disc was heat-treated at 400 °C for 15 min to empty the traps. After each charging, the PersL decay curve was acquired by monitoring the 506 nm emission of Eu^{2+}. (a–c) PersL decay curves acquired after irradiation by a 450 nm LED at light intensities of 2 mW/cm^2, 19.9 mW/cm^2, and 99.4 mW/cm^2, respectively. (d) Relationship of PersL emission intensity (I_{120s}), 450 nm light intensity, and irradiation time. The PersL emission intensities are the intensities acquired at 120 s decay points, as indicated by the dash-lines in (a–c).
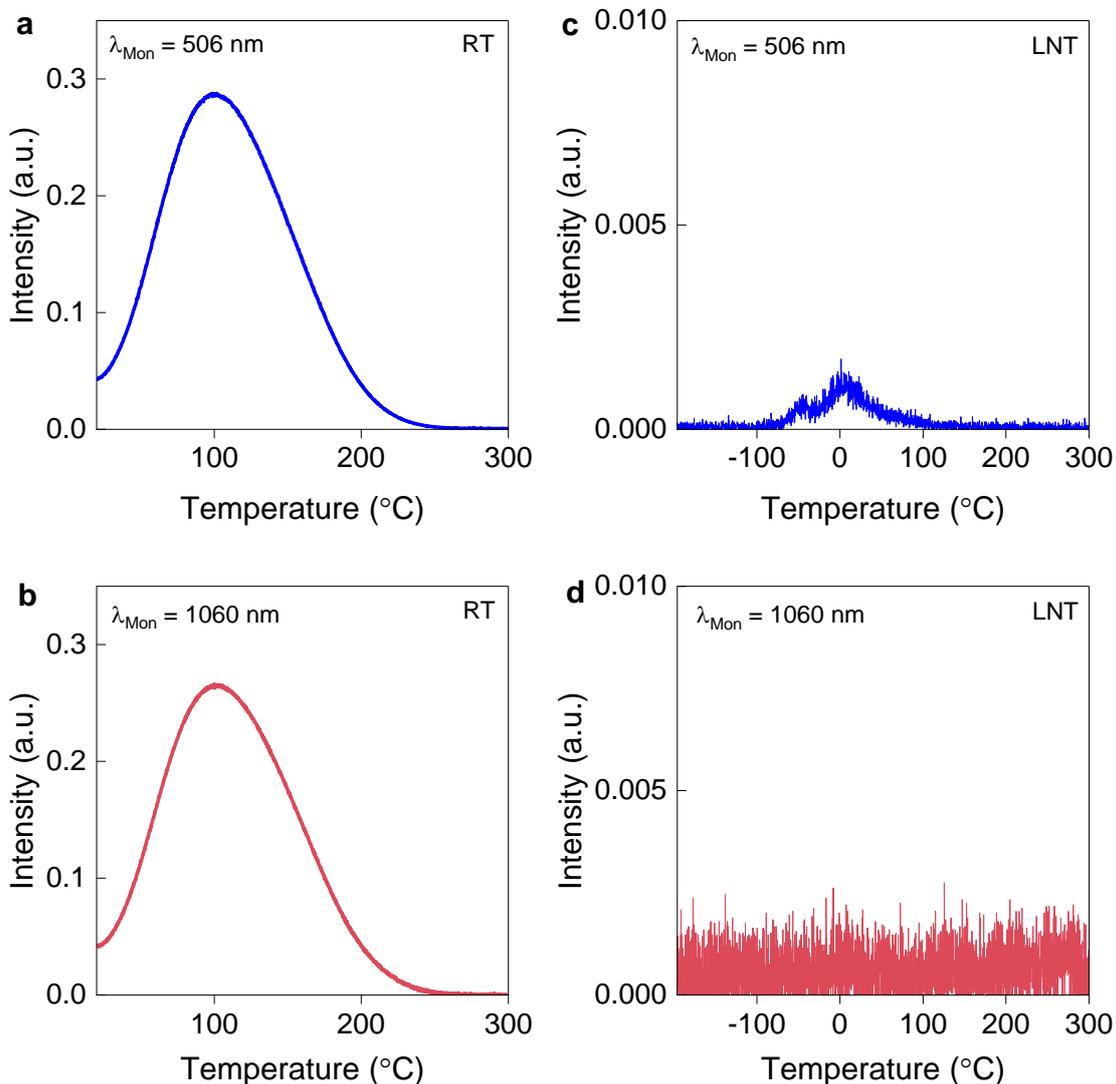
Figure S9 TL curves of SAO:Eu,Nd persistent phosphor charged by 440 nm light at RT or LNT. (a,b) TL curves monitored at 506 nm emission of Eu^{2+} and 1060 nm emission of Nd^{3+} for charging at RT, respectively. The measuring temperature range was 20–300 °C. (c,d) TL curves monitored at 506 nm emission of Eu^{2+} and 1060 nm emission of Nd^{3+} for charging at LNT, respectively. The measuring temperature range was −196–300 °C. These TL curves have already been shown in Fig. 4 of the main text. They are re-displayed here to highlight the difference in charging effect at RT and LNT.
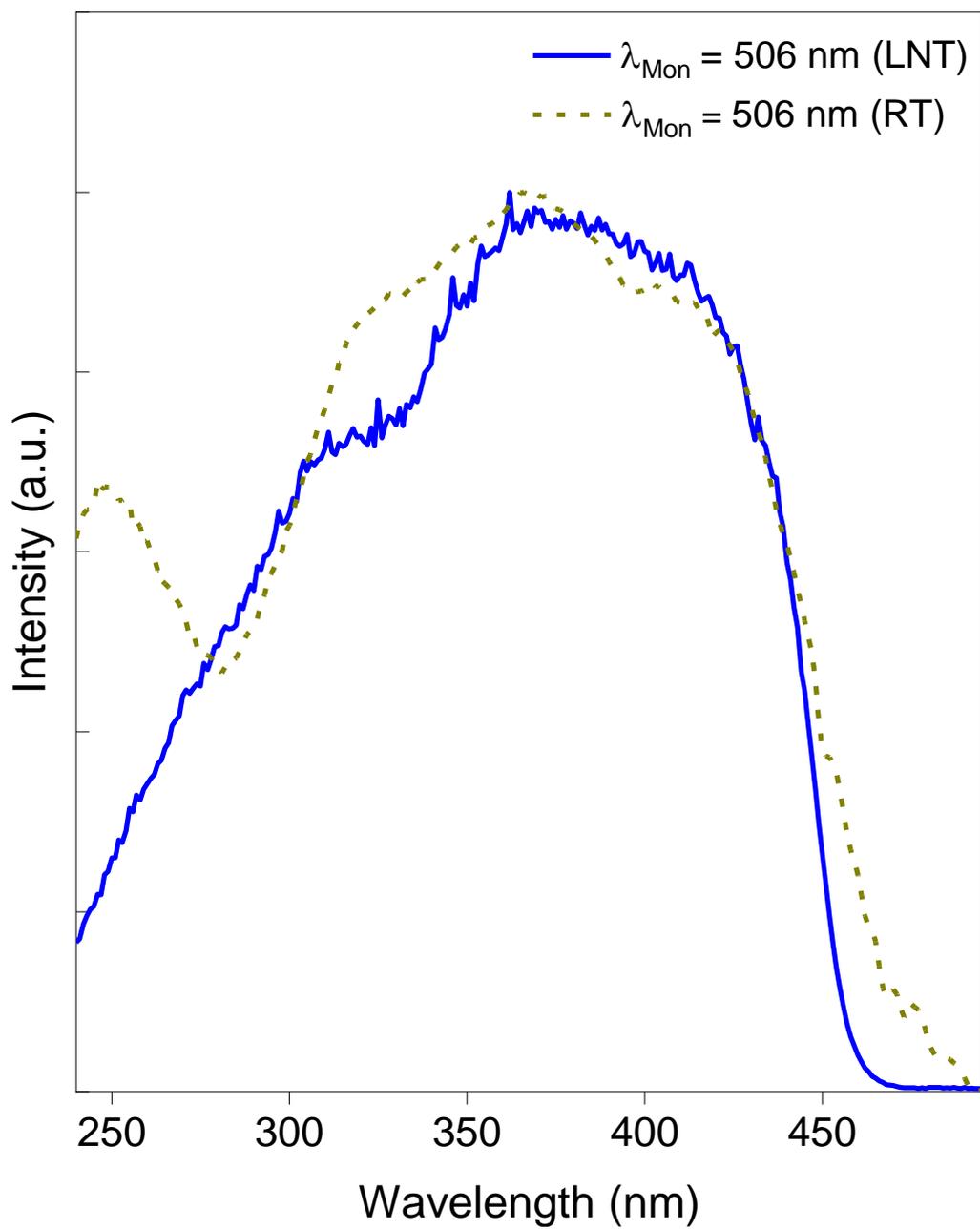
Figure S10 Normalized PL excitation spectra of Eu^{2+} in SAO:Eu,Nd persistent phosphor at LNT and RT. The monitoring wavelength was 506 nm.
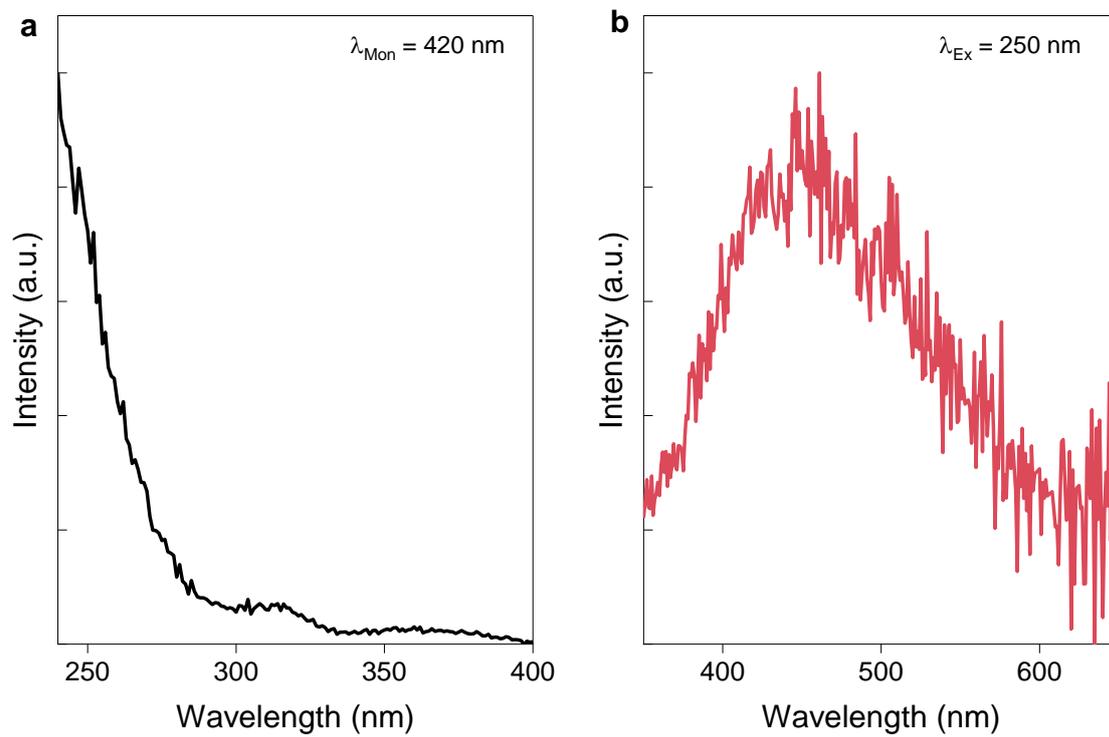
Figure S11 PL excitation and emission spectra of $SrAl_2O_4$ host at RT. The emission spectrum was acquired under 250 nm excitation and the excitation spectrum was obtained by monitoring the 420 nm emission.

Table S1. Determination of the green (Eu^{2+}) and NIR (Nd^{3+}) PersL intensities of SAO:Eu,Nd persistent phosphor at different initial decay instants (10–120 s).

Decay instant (s)	Intensity of green PersL ($\mu W/cm^2$)	Intensity of NIR PersL ($\mu W/cm^2$)
10	61.0	0.69
30	15.4	0.23
60	5.9	0.11
120	2.4	0.07

Measurement note: The measurements were conducted in a dark chamber setup as depicted in the Supplementary Information in ref. 8. A SAO:Eu,Nd phosphor disc was irradiated by a white LED flashlight for 1 min. The green and NIR PersL emission powers (in μW or nW) at different initial decay instants (10–120 s) were collected by a Newport 918D-SL-OD3R silicon photodetector and recorded by a Newport 2936-R optical power and energy meter. The measured powers (in μW or nW) were then calculated into the absolute unit of $\mu W/cm^2$ using a semi-sphere irradiation geometry model by considering the geometry of the dark chamber and the size of the Si detector using equation: $I = I_m \times 2\pi h^2/(\pi \times r^2)$, where I_m is the measured power, h is the distance between sensor and disc, and r is the radius of sensor (see the detail in ref. 8).