Electronic Supplementary Material (ESI) for Journal of Materials Chemistry C.

Near-Infrared $Sr_7NaGa(PO_4)_6:Cr^{3+},Ln^{3+}$ (Ln = Nd, Er, Yb) Phosphors with Different Energy Transfer Paths: Photoluminescence Enhancement and Versatility

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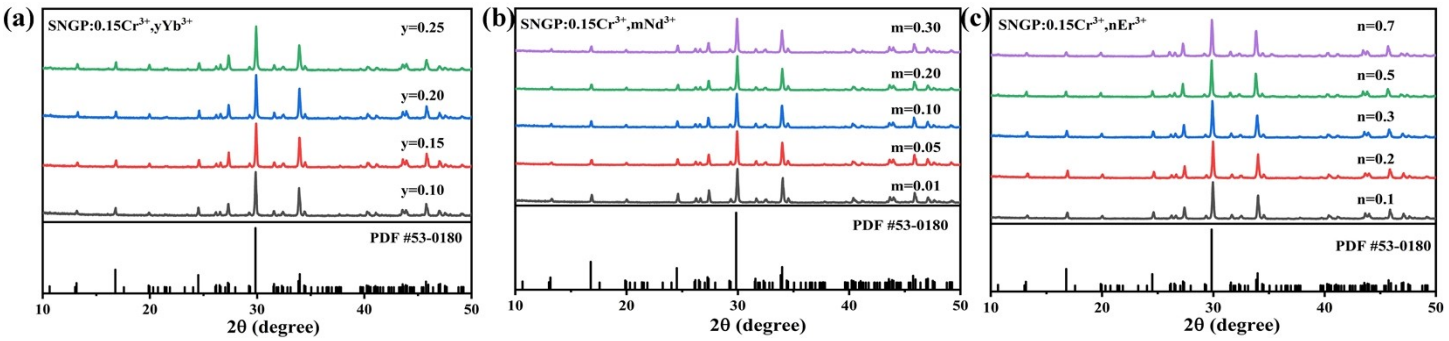

Figure S1: XRD patterns of SNGP:0.15Cr^{3+},*y*Yb^{3+} (*y* = 0.10, 0.15, 0.20, 0.25), SNGP:0.15Cr^{3+},*m*Nd^{3+} (*m* = 0.01, 0.05, 0.10, 0.20, 0.30) and SNGP:0.15Cr^{3+},*n*Er^{3+} (*n* = 0.1, 0.2, 0.3, 0.5, 0.7).

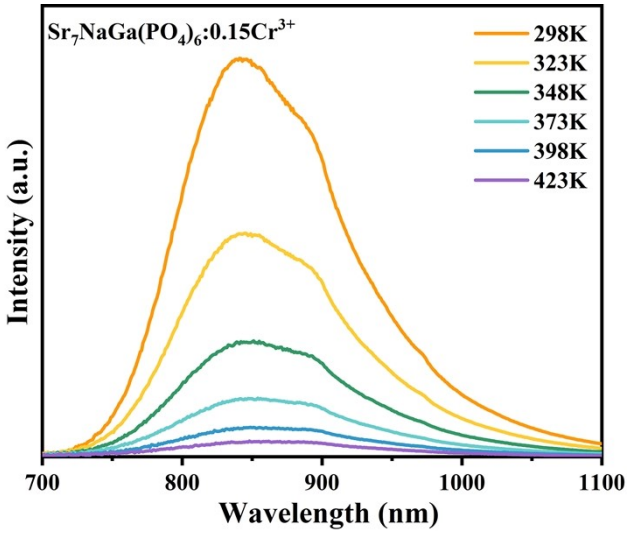

Figure S2. The PL spectra of SNGP:0.15Cr^{3+} at different temperatures.

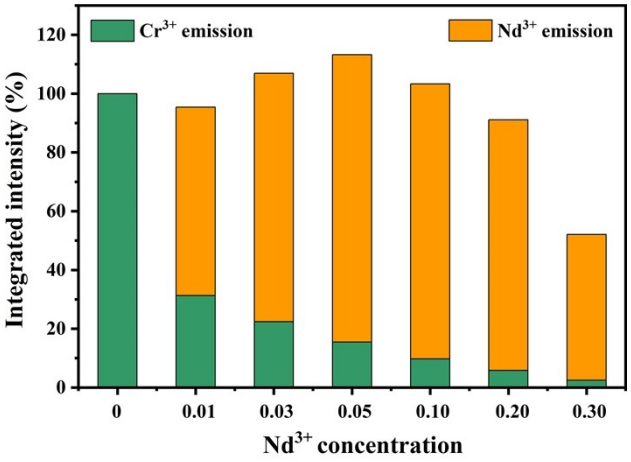

Figure S3. Integrated intensities of the total emission, Cr^{3+}-emission, and Nd^{3+}-emission in SNGP:0.15Cr^{3+},*m*Nd^{3+} phosphors with various Nd^{3+}-concentrations. The total emission is the sum of the Cr^{3+}-emission and Nd^{3+}-emission.

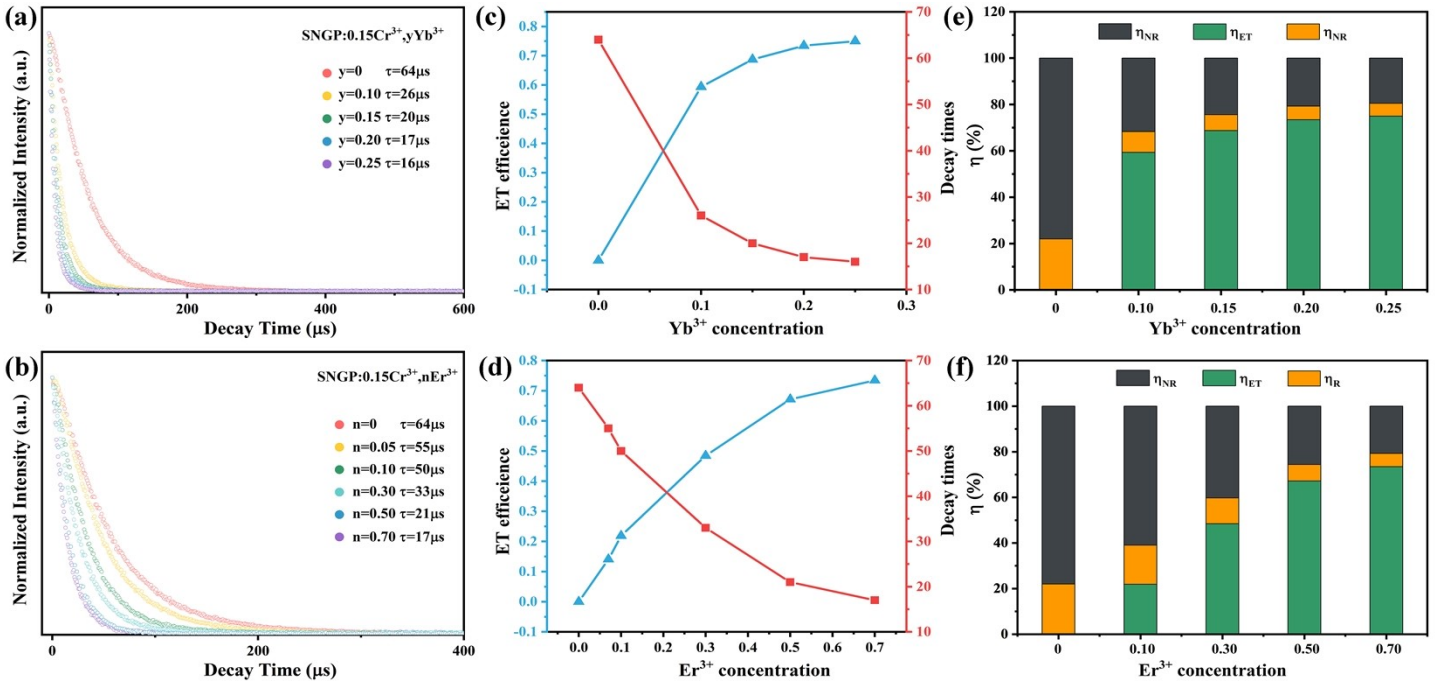

Figure S4 (a) Decay curves of Cr^{3+} (a) in the SNGP:0.15Cr^{3+},*y*Yb^{3+},and (b) in the SNGP:0.15Cr^{3+},*n*Er^{3+}; The values of energy transfer efficiency (η) and decay times of (c) Cr→Yb^{3+} at various Yb^{3+}-concentration, and (d) Cr→Er^{3+} at various Er^{3+}-concentration; Values of η_{ET}, η_R, and η_{NR} of (e) SNGP:0.15Cr^{3+},*y*Yb^{3+}, and SNGP:0.15 Cr^{3+},*n*Er^{3+}.

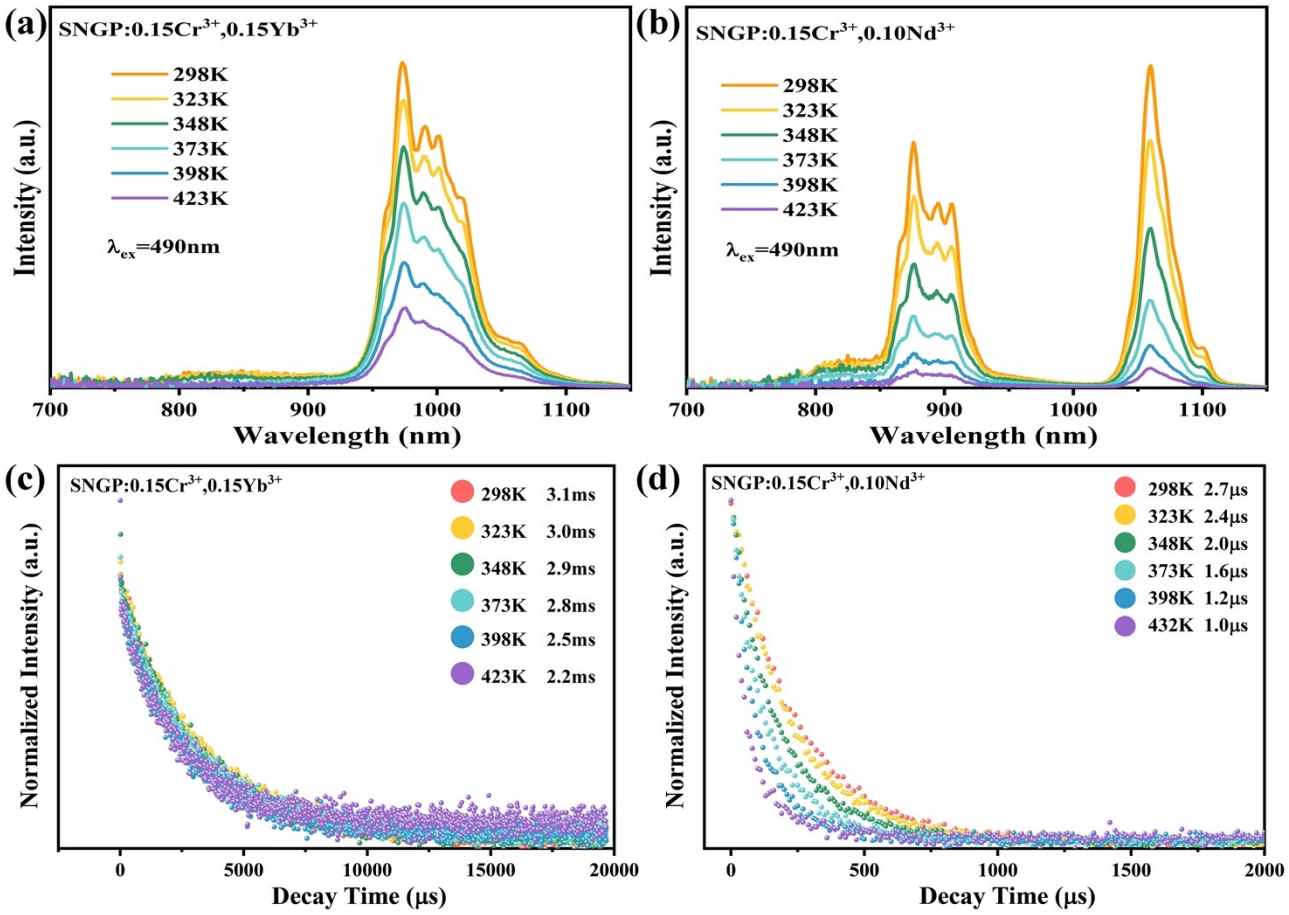

Figure S5, The PL spectra of (a) SNGP:0.15Cr^{3+},0.15Yb^{3+}, and (b) SNGP:0.15Cr^{3+},0.10Nd^{3+} at different temperatures., The decay curves of (c) SNGP:0.15Cr^{3+},0.15Yb^{3+}, and (d) SNGP:0.15Cr^{3+},0.10Nd^{3+} at different temperatures.

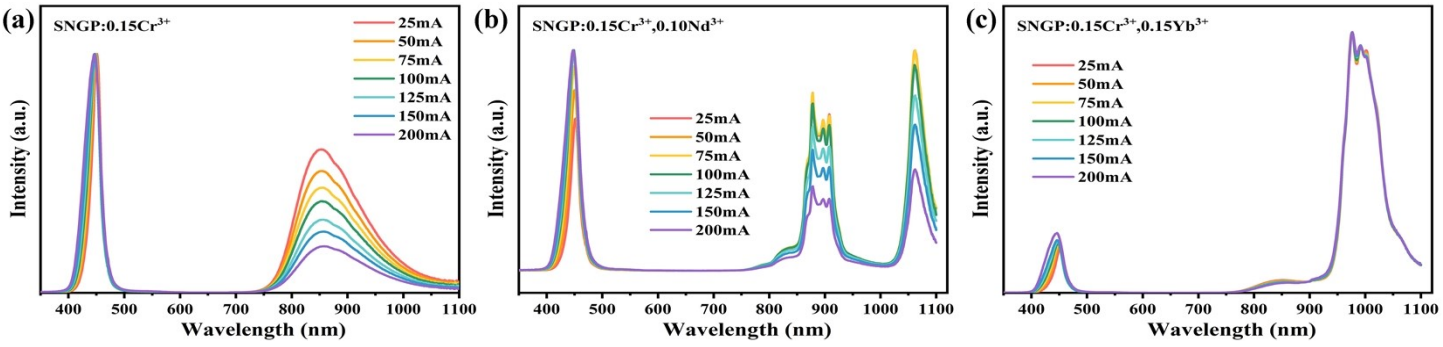

Figure S6, The electroluminescence spectra of (a) SNGP:0.15Cr^{3+}, (b) SNGP:0.15Cr^{3+},0.10Nd^{3+}, and (c) SNGP:0.15Cr^{3+},0.15Yb^{3+} at different driving currents.

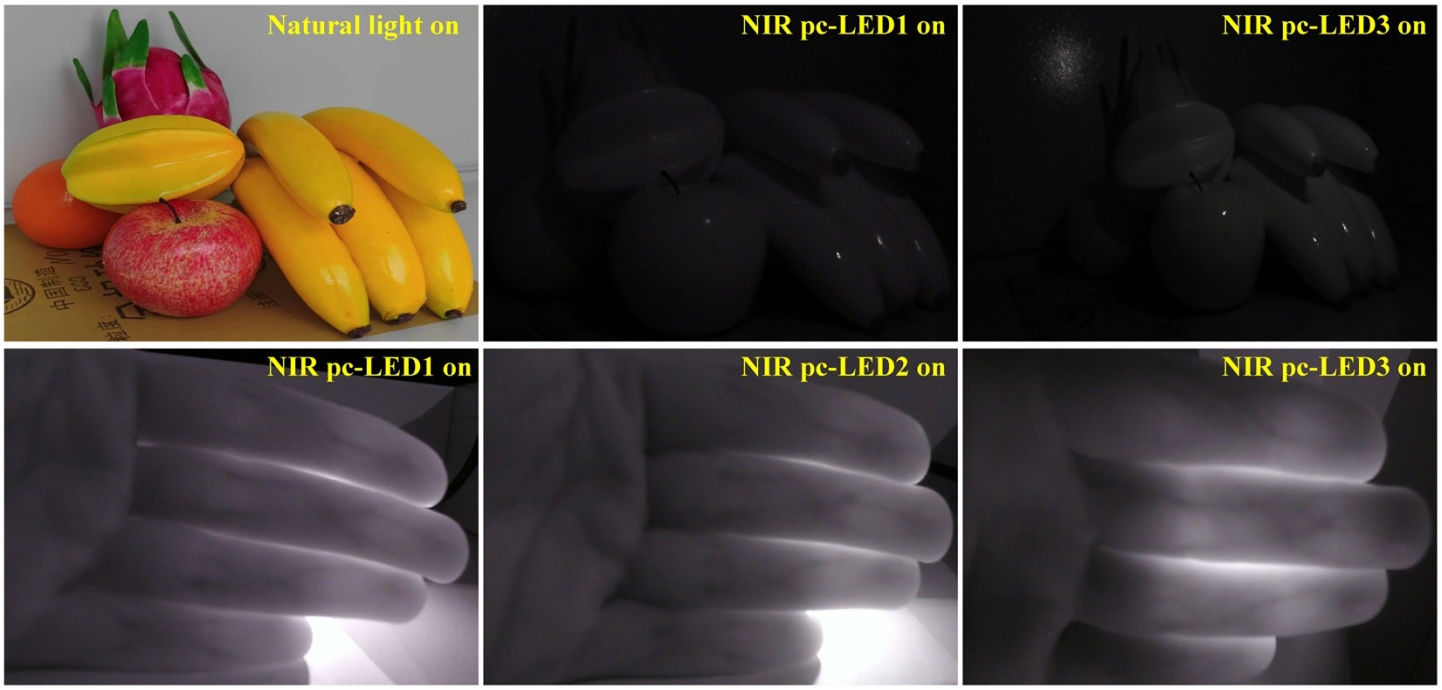

Figure S7 The fruit imagines under the natural light, NIR pc-LEDs 1-3 light. And the fingers under the NIR pc-LEDs 1-3 light.

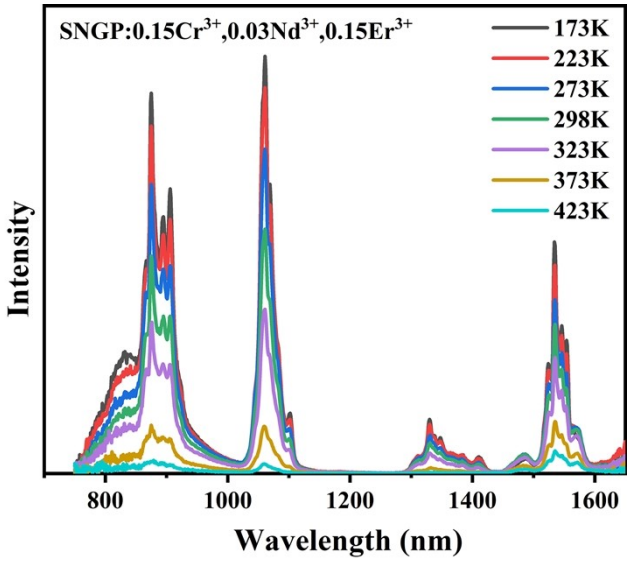

Figure S8 The PL spectra of SNGP:0.15Cr^{3+},0.03Nd^{3+},0.15Er^{3+} at different temperatures.

Table S1 Refined distances of Cr^{3+} and Ln^{3+} corresponding to SNGP:0.15Cr^{3+},0.30Nd^{3+}, SNGP:0.15Cr^{3+},0.70Er^{3+} and SNGP:0.15Cr^{3+},0.25Yb^{3+} phosphors

Name	Distance (Å)	Average Distance (Å)

Nd1_Cr	5.295	4.538
Nd2_Cr	3.781	
Er1_Cr	5.338	4.157
Er2_Cr	3.806	
Er3_Cr	3.746	
Er4_Cr	3.738	
Yb1_Cr	5.324	4.151
Yb2_Cr	3.800	
Yb3_Cr	3.744	
Yb4_Cr	3.736	

Supplementary Note1

When the critical distance exceeds 5 Å, the energy transfer mechanism belongs to multipolar interaction. The multipolar interaction type is calculated by the following equation:[1]

$$\log\left(I/x\right) = A - \left(\theta/3\right)\log x$$

Where x is the concentration of Cr^{3+}, and A is a constant. Van Uitert defined θ = 6, 8, 10 as corresponding to dipole–dipole, dipole–quadrupole, and quadrupole–quadrupole interactions, respectively. As shown in Figure S9, the slop is -1.72, thus the θ is similar to 6 and the multipolar interaction belongs to d-d interaction.

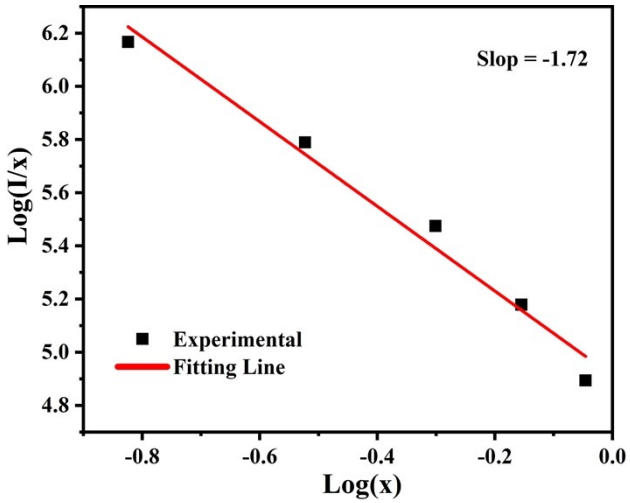

Figure S9 Dependence of log(I/x) versus log x for SNGP:xCr^{3+}.

Supplementary Note2

The IQEs of SNGP:0.15Cr^{3+},0.15Yb^{3+}, SNGP:0.15Cr^{3+},0.10Nd^{3+} and SNGP:0.15Cr^{3+},0.5Er^{3+} can be calculated by the following formula:[2]

$$\eta_{IQE} = \frac{\int L_S}{\int E_R - \int E_S}$$

Where L_S represents the emission spectrum of sample, E_R and E_S relate to the excitation spectra of sample and $BaSO_4$ reference, respectively. Notably, the PL spectrum exceeding 960 nm of the sample is not detected due to the instrument limitation, which caused the IQE of samples is lower than real IQE. The real IQE can be obtained by the equation as follows:

$$\eta_r = \frac{\eta_{IQE} \times \int L_{S'}}{\int L_S} + \eta_{IQE}$$

Where η_r represents the real IQE of the sample, $L_{S'}$ stands for the emission spectrum undetected by instrument.

Reference

1. C. Zhong, L. Zhang, Y. Xu, X. Wu, S. Yin, X. Zhang and H. You, *J. Alloy. Compd.* , 2022, **903**, 163945.

2. S. Wang, H. Wu, Y. Fan, Q. Wang, T. Tan, R. Pang, S. Zhang, D. Li, L. Jiang, C. Li and H. Zhang, *Chem. Eng. J.*, 2022, **432**, 134265.