# Electronic supplementary information

## Highly efficient and thermally stable broadband near-infrared emitting garnet $Ca_3Sc_2Ge_3O_{12}:Cr^{3+}$, $Ce^{3+}$ for multiple pc-LED applications

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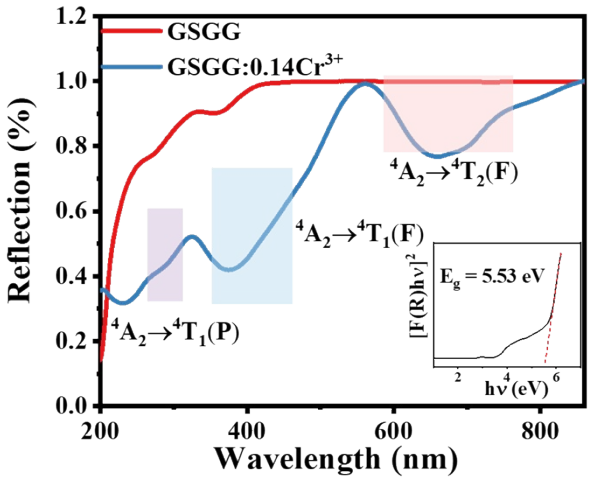


**Fig. S1** Diffuse reflectance spectra (DRS) of CSGG:x$Cr^{3+}$ (x = 0, 0.14).

(1) The band gap ($E_g$) values of the host can be evaluated by the Kubelka-Munk equations:

$$F(R) = (1 - R)^2/2R \qquad (S1)$$

$$[F(R) \times h\upsilon]^2 = A(h\upsilon - E_g) \qquad (S2)$$

where *F(R)* represents the absorption, *R* is the reflectance (%), and *hv* is the incident photon energy, A is a constant, $E_g$ is the bandgap value. Based on the DRS, the $E_g$ values of CSGG hosts were determined to be 5.53 eV.

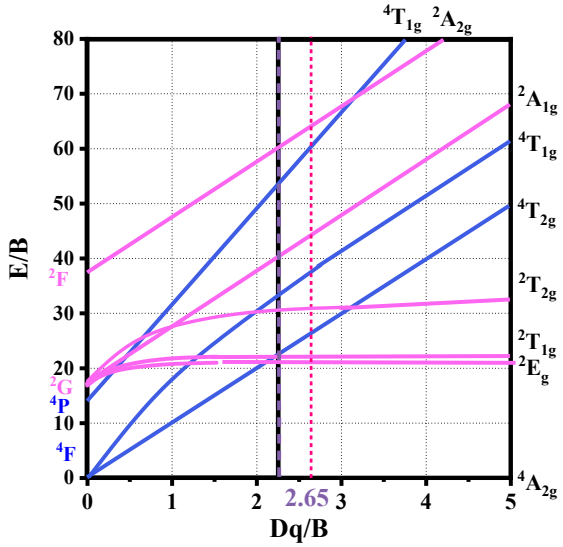


**Fig. S2** Tanabe-Sugano diagram for a $Cr^{3+}$ ion in octahedral coordination. Dq/B value of $Cr^{3+}$ in GSGG are marked in the Figure.

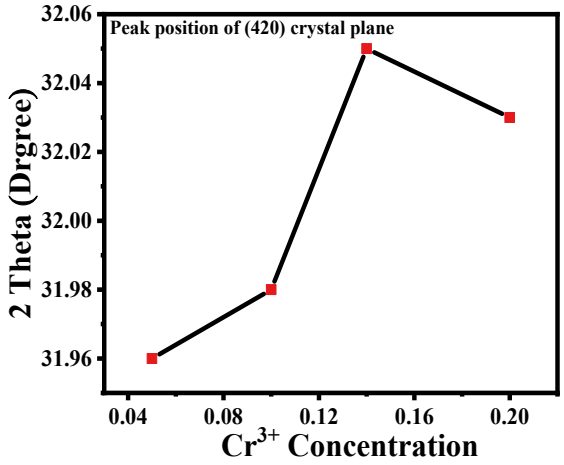


**Fig. S3** Variation of the shift of the diffraction peak on the (420) crystal plane with increasing doping of $Cr^{3+}$.

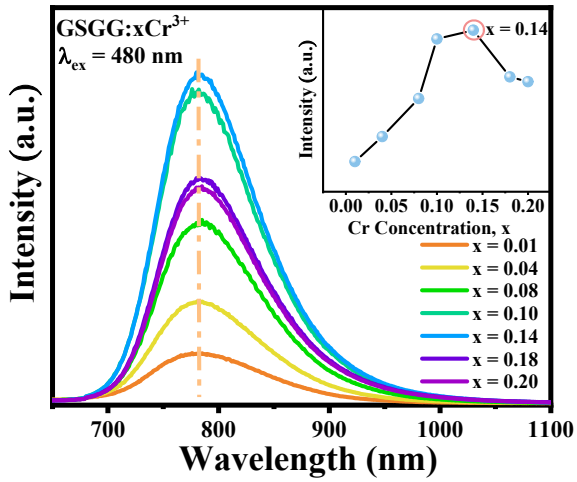


**Fig. S4** Concentration-dependent emission spectra of CSGG:x$Cr^{3+}$ (x = 0.01, 0.04, 0.08, 0.10, 0.14, 0.18, 0.20) phosphors. The upper inset shows the integral emission intensity under different $Cr^{3+}$ doping concentrations.

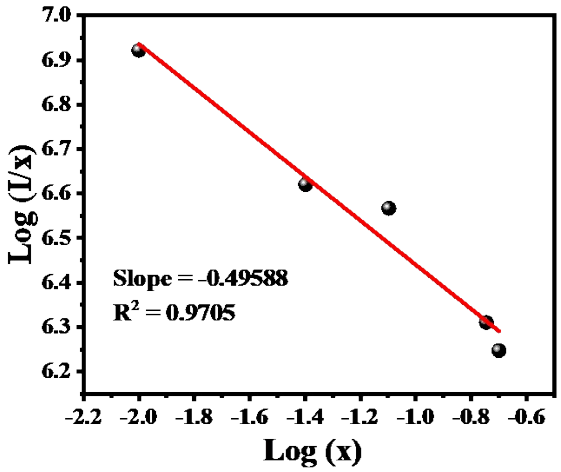


**Fig. S5** Relationship between log (I/x) and log x of GSGG:x$Cr^{3+}$.

The mechanism can be obtained using the following formula:

$$\log\left(\frac{I}{x}\right) = A - \frac{\theta}{3}logx$$

Where I is the emission intensity, x is the concentration of the activator ions above the quenching concentration, β and K are constant for the same excitation conditions. The θ = 3 represents the interaction type of the energy transfer between the nearest-neighboring ions, while θ = 6, 8, and 10 represent dipole-dipole, dipole-quadrupole, and quadrupole-quadrupole interactions, respectively.

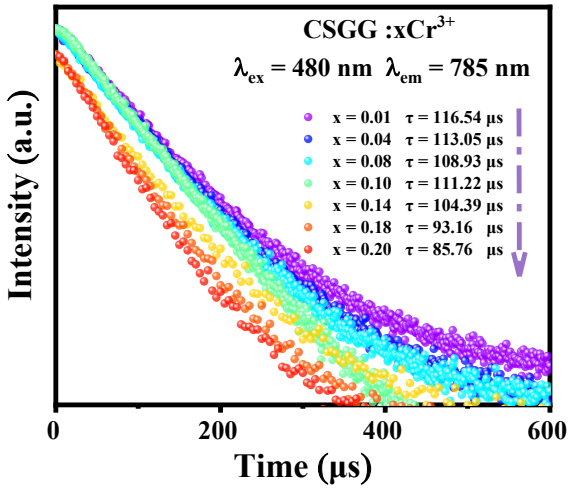


**Fig. S6** Decay curves of CSGG:x$Cr^{3+}$ phosphor under different $Cr^{3+}$ doping concentrations.

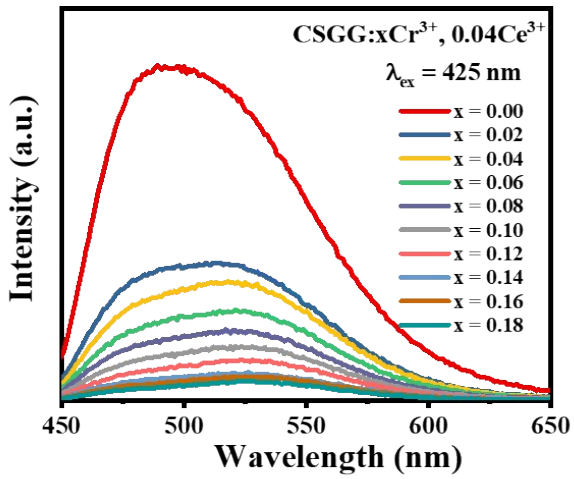


**Fig. S7** The emission spectra of CSGG:x$Cr^{3+}$, 0.04$Ce^{3+}$ (x = 0-0.18) in the NIR range.

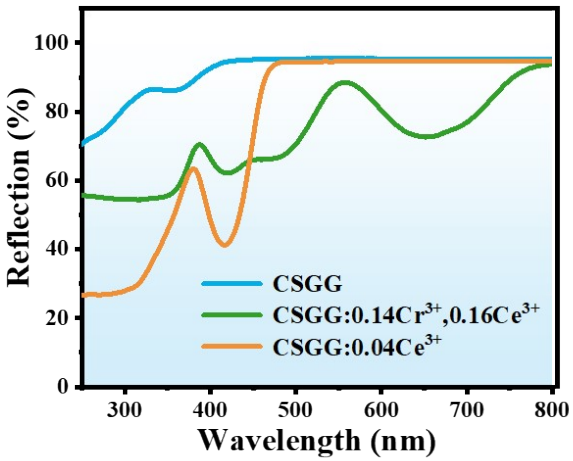


**Fig. S8** DRS of CSGG host, CSGG:0.14$Cr^{3+}$, 0.16$Ce^{3+}$, and CSGG:0.04$Ce^{3+}$.

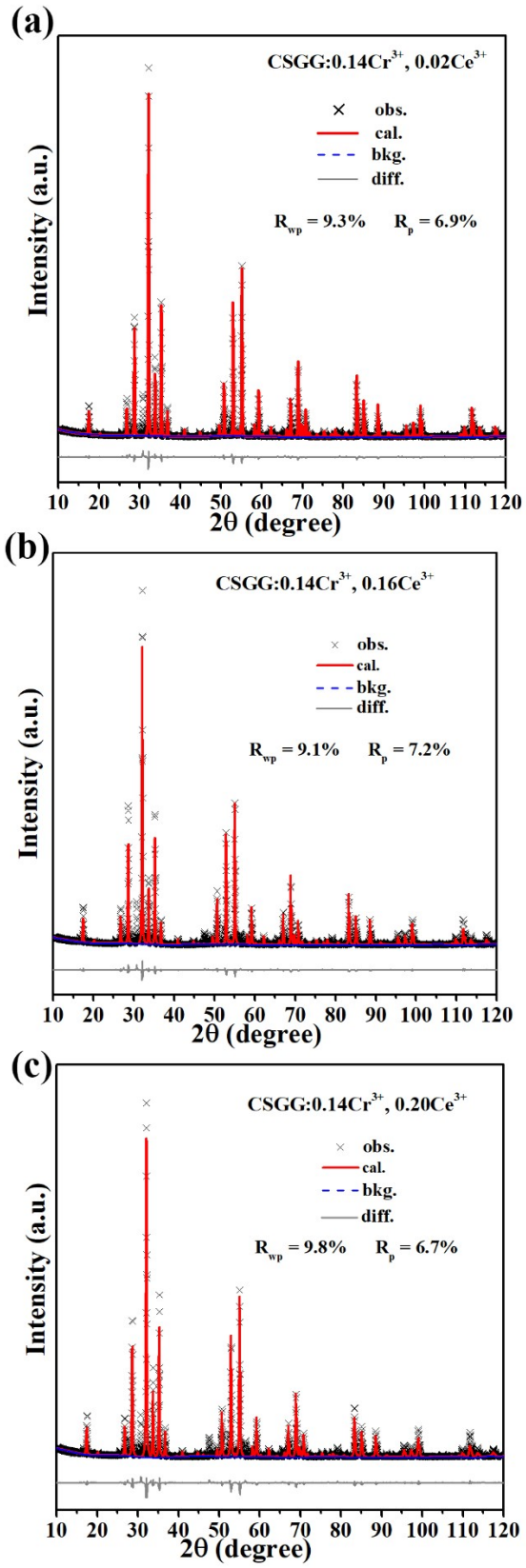


**Fig. S9** XRD Rietveld refinement of (a) CSGG:0.14$Cr^{3+}$, 0.02$Ce^{3+}$, (b) CSGG:0.14$Cr^{3+}$, 0.16$Ce^{3+}$, and (c) CSGG:0.14$Cr^{3+}$, 0.20$Ce^{3+}$.

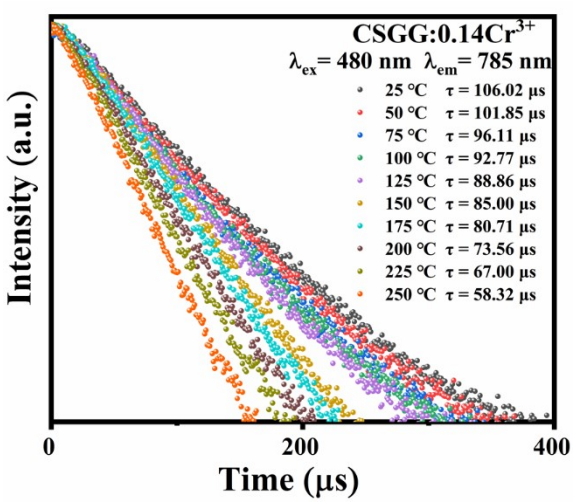


**Fig. S10** Decay curves of CSGG:0.14$Cr^{3+}$ phosphors at different temperatures.

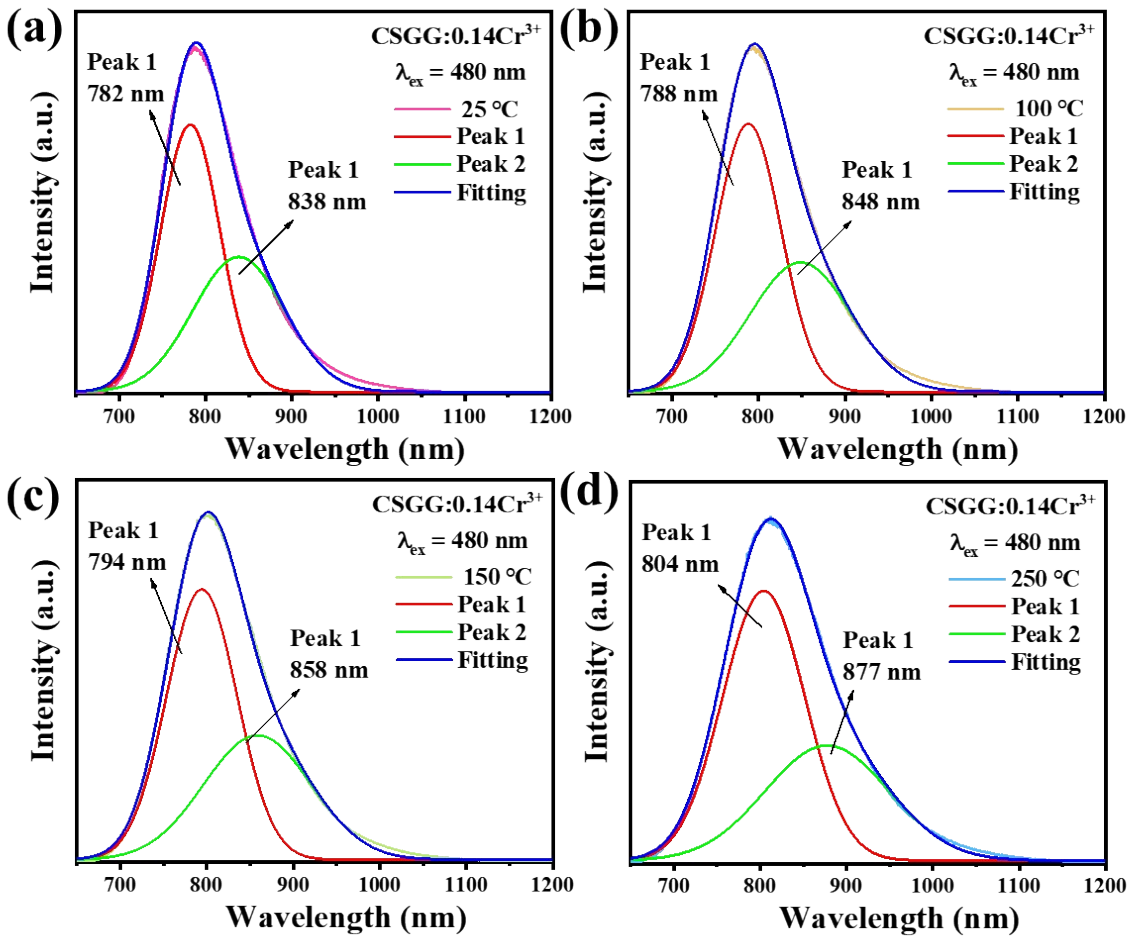


**Fig. S11** The PL spectrum and corresponding Gaussian fitting of CSGG:0.14$Cr^{3+}$ phosphor recorded at (a) 25 °C, (b)100 °C, (c)150 °C, and (d)250 °C.

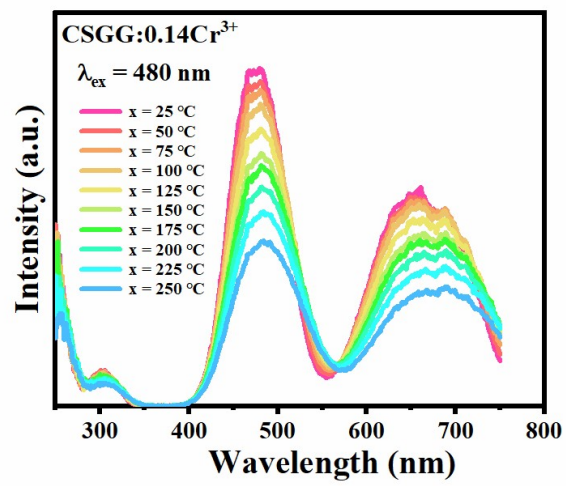


**Fig. S12** Temperature-dependent excitation spectra of CSGG:0.14$Cr^{3+}$.

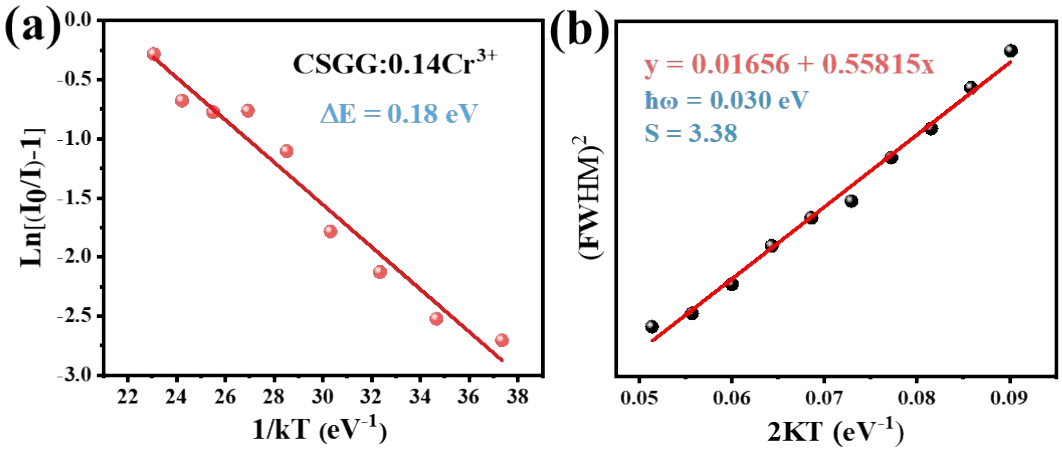


**Fig. S13** (a) Variable temperature spectra of Ln[($I_0$/I)-1] versus 1/kT were plotted.

(b) Fitting FWHM curve with temperature.

**Table S1** Main parameters of processing and refinement results of CSGG:0.14$Cr^{3+}$, y$Ce^{3+}$ ($y$ = 0.02, 0.16, 0.20).

| CSGG:$Cr^{3+}$ | **y = 0.02** | **y =0.16** | **y = 0.20** |
|---|---|---|---|
| Space group | *Ia*3*d* | *Ia*3*d* | *Ia*3*d* |
| $a$=$b$=$c$, Å | 12.500594(235) | 12.502334(264) | 12.506791(160) |
| $V$, Å$^3$ | 1953.403(110) | 1954.219(124) | 1956.310(75) |
| α = β = γ | 90° | 90° | 90° |
| $R_{wp}$, % | 9.3 | 9.1 | 9.8 |
| $R_p$, % | 6.9 | 7.2 | 6.7 |
| $\chi^2$ | 2.401 | 2.386 | 2.391 |

**Table S2.** Selected bond length (Å) of CSGG:0.14$Cr^{3+}$, y$Ce^{3+}$ ($y$ = 0.02, 0.16, 0.20).

| | y = 0.02 | y = 0.16 | y = 0.20 |
|---|---|---|---|
| 8×Ca—O | 4×2.4370 (2)<br>4×2.50086 (5) | 4×2.42306 (4)<br>4×2.50684 (3) | 4×2.40094 (4)<br>4×2.51506 (5) |
| Average bond length | 2.47192 | 2.46495 | 2.45800 |
| *D** | 1.41% | 1.70% | 2.32% |

(*lattice distortion index $D = \frac{1}{n}\frac{\sum_{i=1}^{n}|d_{av} - d_i|}{d_{av}}$)