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Supporting Information

Highly efficient and thermally stable broadband Cr^{3+}-activated double borate phosphor for near-infrared light-emitting diodes

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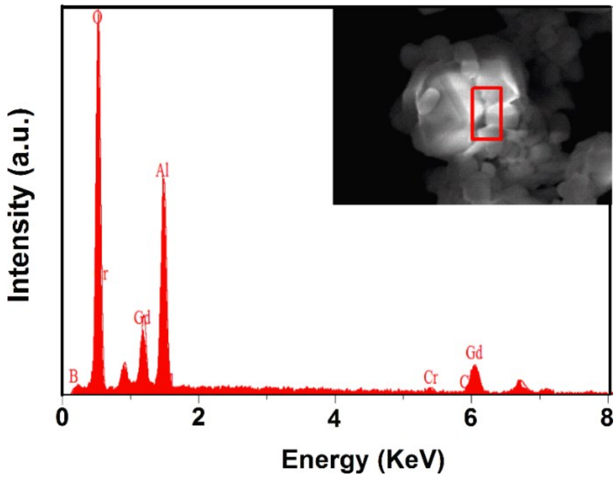

Fig. S1. EDS spectrum of the GAB: Cr^{3+} (1.0 at.%) sample.

Table S1. Crystallographic data determined from Rietveld refinement for $GdAl_{2.99}Cr_{0.01}(BO_3)_4$ and $GdAl_3(BO_3)_4$ crystals.

Formula	$GdAl_{2.99}Cr_{0.01}(BO_3)_4$	$GdAl_3(BO_3)_4$
Crystal system	Trigonal	Trigonal
Space group	*R*32	*R*32
a(Å)	9.3107(6)	9.3014(7)
b(Å)	9.3107(6)	9.3014(7)
c(Å)	7.2612(4)	7.2571(7)
V(Å^3)	545.12	543.74
α (°)	90	90
β (°)	90	90
γ (°)	120	120
R_p(%)	6.56	—
R_{wp}(%)	4.56	—
χ^2	2.68	—

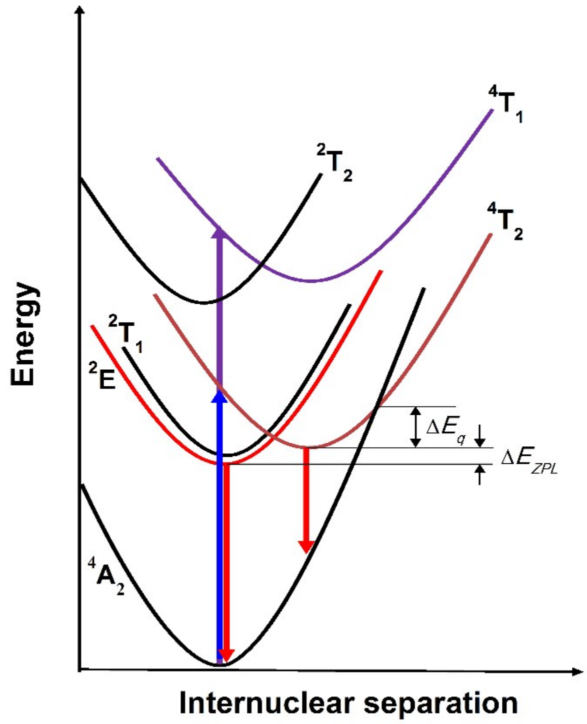

Fig. S2. Configurational coordinate diagram of Cr^{3+} ions in GAB crystal. ΔE_q is the activation energy, ΔE_{ZPL} is the energy gap between $^2E(^2G)$ and the $^4T_2$ (^4F) ZPL.

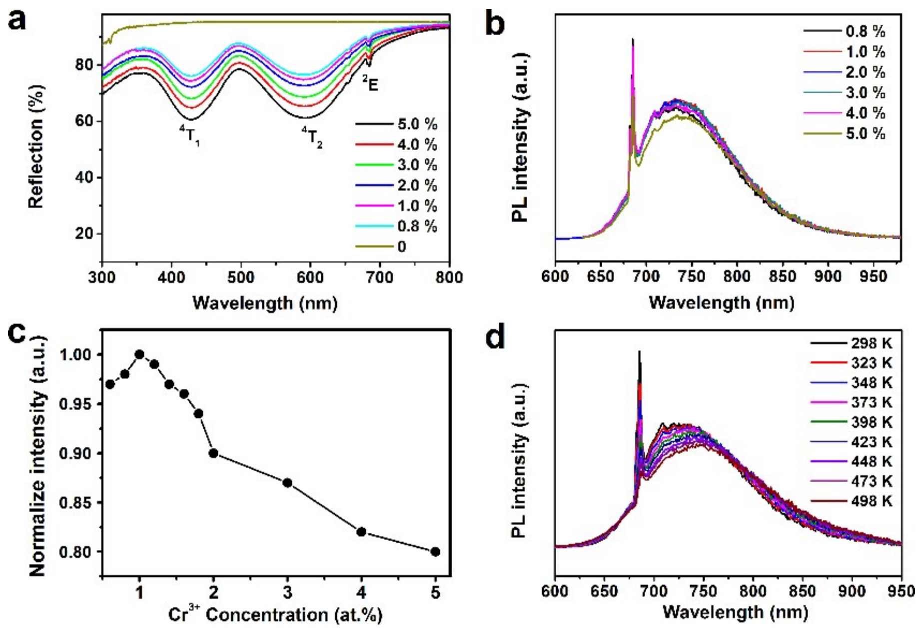

Fig. S3. (a) Diffuse reflection spectra and (b) PL spectra of GAB:Cr^{3+} samples with Cr^{3+} doping concentrations of 0.8–5.0 at.% (λ_{ex} = 426 nm). (c) The Cr^{3+} concentration dependent normalized PL intensity. (d) Temperature-dependent emission spectra of GAB:Cr^{3+} (1.0 at.%) upon excitation at 426 nm.

Table S2. Several key optical parameters of Cr^{3+}-activated phosphors.

Phosphor	Emission range	PL QY(%)	$I_{423\,k}/ I_{298\,k}$ (%)	Ref.
$GdAl_3(BO_3)_4:Cr^{3+}$	650-1000 nm	91	100	This work
$LiInSi_2O_6:Cr^{3+}$	700-1100 nm	75	77	1
$Ca_3Sc_2Si_3O_{12}:Cr^{3+}$	650-1000 nm	92.3	97.4	2
$Ga_2O_3:Cr^{3+}$	650-900 nm	92.4	~85	3
$Na_3AlF_6:Cr^{3+}$	640-850 nm	~75	~71	4
$Ca_2LuZr_2Al_3O_{12}:Cr^{3+}, Yb^{3+}$	650-1100 nm	~77	~60	5
$ScBO_3:Cr^{3+}$	650-1000 nm	~73	51	6
$La_3Ga_5GeO_{14}:Cr^{3+}, Pr^{3+}$	650-1400 nm	~39	15	7
$La_3Ga_5GeO_{12}:Cr^{3+}$	650-950 nm	35	~60	
$Gd_3Sc_{1.42}Al_{0.5}Ga_3O_{12}:8\%Cr^{3+}$	650-1000 nm	91	86	8
$La_3Sc_2Ga_3O_{14}:Cr^{3+}$	650-1400 nm	~8	20	9
$Y/Gd/Lu_3Sc_2Ga_3O_{12}: Cr^{3+}$	650-1100 nm	~60	~93	
$Mg_3Ga_2GeO_8:Cr^{3+}$	650-1200 nm	~35	~55	10
$K_3Ga/AlF_6:Cr^{3+}$	650-1000 nm	___	~40	11
$La_2MgZrO_6:Cr^{3+}$	650-1200 nm	~58	~30	12
$Y_3Ga_5O_{12}: Cr^{3+}$	600-1000 nm	~46	___	13
$Gd_3Ga_5O_{12}: Cr^{3+}$	600-1000 nm	~30	___	
$LaMgGa_{11}O_{19}:Cr^{3+}$	650-1000 nm	82.6	~87	14

Supplementary Discussion: The D_q parameter is obtained from the peak energy of the $^4A_2 \rightarrow {}^4T_2$ transition, while Racah parameters B and C can be estimated by the following equations:[15]

$$E(^4T_2 - {}^4A_2) = 10D_q \quad (1)$$

$$\frac{B}{D_q} = \frac{(\Delta E/D_q)^2 - 10(\Delta E/D_q)}{15(\Delta E/D_q - 8)} \quad (2)$$

$$3.05C = E(^2E) - 7.9B + 1.8B^2/\Delta E \quad (3)$$

where $\Delta E = [E(^4T_1) - E(^4T_2)]$ is the difference between the energies of the $^4T_1$ and $^4T_2$ states and $E(^2E)$ is the energy of the ^2E state. The value of $^4T_1$, $^4T_2$ and ^2E are estimated to be 23470, 16730 and 14598 cm^{-1} from the excitation and emission bands, respectively. Based on equations (1) - (3), the values of B, C and D_q/B were calculated to be 675 cm^{-1}, 3197 cm^{-1} and 2.48, respectively.

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