# Supporting Information

## Modulating Anti-Thermal and Concentration Quenching for Enhanced Dysprosium Emission

Wasim Ullah Khan[a,b], Haris Zaman[b], Waheed Ullah Khan[a], Haiou Zhu[a, *]

*a. Analysis and Testing Center, Shenzhen Technology University/College of new Materials and new Energies, Shenzhen Technology University, Pingshan Shenzhen, 518118 P.R. China.*

*b. Institute of Chemical Sciences University of Peshawar, Pakistan.*

**Corresponding Author**

*Email: zhuhaiou@sztu.edu.cn

**Table S1.** Fraction Atomic Coordinates and Equivalent Isotropic Displacement Parameters ($Å^2$) for SLAB:0.015$Tm^{3+}$,$Dy^{3+}$.

| Atoms | Site | X | Y | Z | $U_{iso}$ | N |
|---|---|---|---|---|---|---|
| Sr1/La1 | 2c | 0.333/0.333 | 0.666/0.666 | 0.250/0.250 | 0.0121(13) | 0.202/0.797(14) |
| Sr2/La2 | 6h | 0.128/128(5) | 0.840/0.840(5) | 0.250/0.250 | 0.99(2) | 0.98/0.12(5) |
| Al | 6g | 0 | ½ | 0 | 0.0160(15) | 1 |
| B1 | 6h | 0.2168(3) | 0.7636(3) | ¾ | 0.004(5) | 1 |
| B2 | 4e | 0 | 0 | -0.0899(12) | 0.04(2) | ½ |
| O1 | 12i | 0.3407(13) | 0.9233(12) | ¼ | 0.016(4) | 1 |
| O2 | 12i | 0.3006(2) | 0.4660(14) | 0.5369 | 0.019(4) | 1 |
| O3 | 6h | -0.0435(9) | 0.1037(8) | 0.4071(12) | 0.010(2) | 1 |
| O4 | 6h | 0.08261(3) | 0.4637(3) | o.2500(3) | 0.016(4) | 1 |

Space group *P63/m*: *a* = *b* = 10.3867(3) A˚, *c* = 5.8146(4) A˚, Reliability factor: $R_p$ = 0.0275, $R_{wp}$ = 0.0453.

**Table S2.** Some selected bond lengths of SLAB:0.015$Tm^{3+}$,0.05$Dy^{3+}$ phosphor.

| Atoms | SLAB:0.015$Tm^{3+}$,0.05$Dy^{3+}$ |
|---|---|
| Sr1/La1–O1 | 2.281(11) Å X 3 |
| Sr1/La1–O3 | 2.295(7) Å X 6 |
| Sr2/La2–O1 | 2.353(11) Å X 1 |
| Sr2/La2–O2 | 2.205(11) Å X 1 |
| Sr2/La2–O3 | 2.335(8) Å X 2 |
| Sr2/La2–O4 | 2.446(2) Å X 1 |
| Sr2/La2–O4 | 2.420(3) Å X 1 |
| Sr2/La2–O4 | 2.423(3) Å X1 |
| Al–O1 | 1.926(7) Å X 2 |
| Al–O2 | 2.080(10) Å X2 |
| Al–O3 | 1.796(8) Å X 2 |
| B1–O2 | 1.305(3) Å X 1 |
| B1–O3 | 1.347(2)Å X 2 |
| B2–O4 | 1.712(13) Å X 3 |

**Table-S3.** Lifetimes, fitting Parameters, energy transfer rates, and quantum efficiency for SLAB:$Tm^{3+}$,x$Dy^{3+}$ (x = 0 to 0.15) from measurements of $Dy^{3+}$ emission at RT.

| $Sm^{3+}$ | $R^2_{adj}$ | τ* | $^{a}k_{ET}$ $(\mu s)^{-1}$ | η (%) |
|---|---|---|---|---|
| 0 | 0.9995 | 22.35 | 0.00 | 0.0 |
| 0.01 | 0.9993 | 20.07 | 5.08 | 11.70 |
| 0.05 | 0.9979 | 16.13 | 17.64 | 29.01 |
| 0.10 | 0.9953 | 10.83 | 47.61 | 52.84 |
| 0.15 | 0.9918 | 6.53 | 88.77 | 70.23 |

**Table-S4.** Calculated $D_{uv}$ value of color quality and chromaticity shift (ΔE) of SLAB:0.015$Tm^{3+}$,0.05$Dy^{3+}$ along with various temperatures.

| | Color coordinates | | | |
|---|---|---|---|---|
| Value of x | X | Y | $D_{uv}$ | $(\Delta E)\times10^{-3}$ |
| 300 K | 0.321 | 0.335 | 0.0023 | 0.00 |
| 350 K | 0.324 | 0.330 | - 0.0014 | 8.31 |
| 400 K | 0.322 | 0.328 | - 0.0020 | 8.90 |
| 450 K | 0.318 | 0.322 | - 0.0073 | 9.12 |
| 500 K | 0.313 | 0.317 | -0.0032 | 10.31 |

## Supplementary Figures and Tables

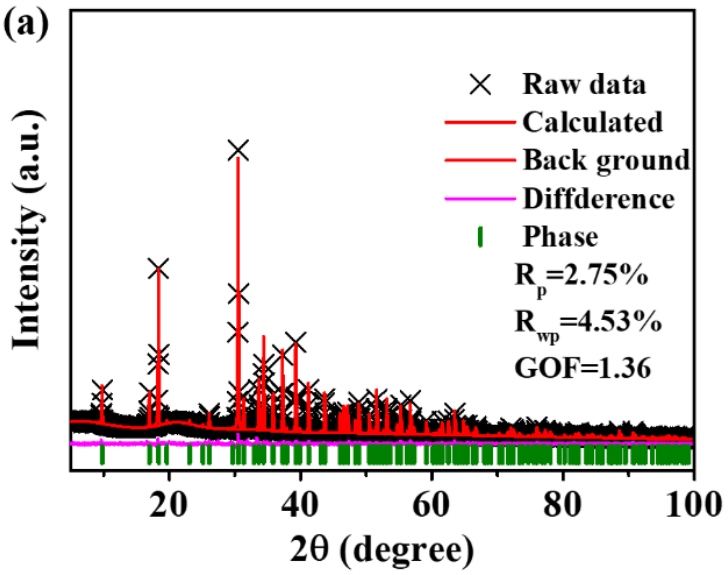


**Fig. S1.** Rietveld refinement result of the SLAB:0.015$Tm^{3+}$,0.10$Dy^{3+}$.

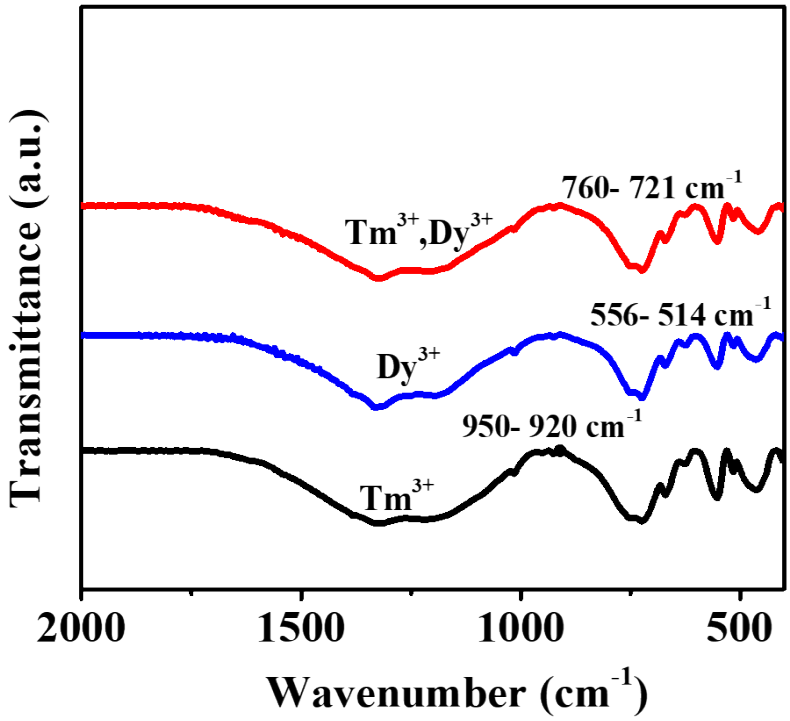


**Fig. S2.** FTIR spectra of singly doped and codoped $Tm^{3+}$,$Dy^{3}$ phosphors.

The absorption peak between 200 and 290 nm corresponds to the host, while the peaks between 200 and 500 nm are attributed to transitions involving $Tm^{3+}$ or $Dy^{3+}$ ions. Such an interpretation is compatible with the f-f transitions observed in their PLE spectrum. The bandgap for the host material is typically calculated using the formula below.

$$F(R_\infty) = \frac{A(1-R)}{2R} = K/S \qquad \text{(S1)}$$

The absorption, the scattering coefficient, and the reflections are denoted by the letters K, R, and S in this instance. The estimated value of Eg is approximately 4.96 eV (**Fig. 3b**), derived from the linear extrapolation of $[F(R_\infty)hv]^2 = 0$.

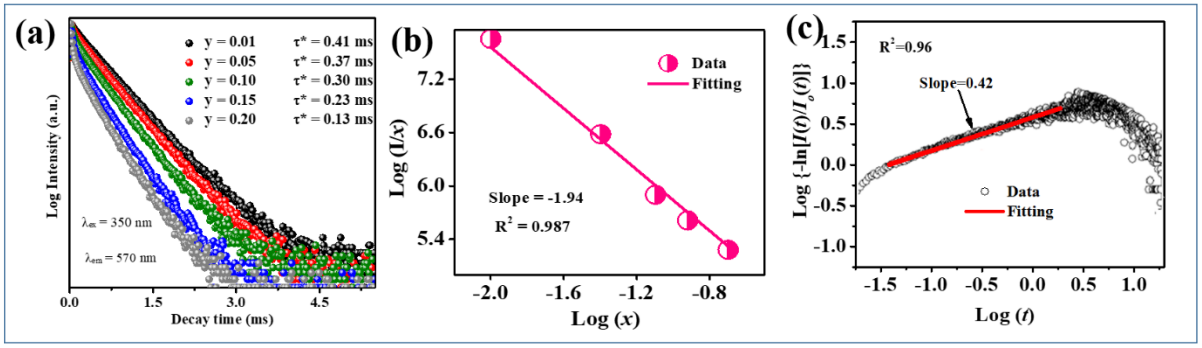


**Fig. S3.** **(a)** Decay times of the SLAB:yDy$^{3+}$. **(b)** The linear relationship of log(I/x) vs log(x) and **(c)** the fitting with the Inokuti-Hirayama model of the SLAB:yDy$^{3+}$.

The distance between ions can be estimated using an equation.

$$R \approx 2\left[\frac{3V}{4\pi x_c N}\right]^{1/3} \qquad \text{(S2)}$$

In which $V$ is referred to as cell volume, $N$ is the number of molecules in the unit cell, and $x_c$ is the total concentration of Tm$^{3+}$ and Dy$^{3+}$. For the SLAB:0.015Tm$^{3+}$,0.08Dy$^{3+}$ host with N=2, V=546.45 Å$^3$ (denoting the cell volume), and a concentration of Tm$^{3+}$ and Dy$^{3+}$ at 0.095, the computed critical distance is approximately 17.65 Å. This estimation suggests a minimal possibility for ET through exchange interaction due to the relatively large distance between ions, showing a tiny possibility for ET through the exchange interaction.

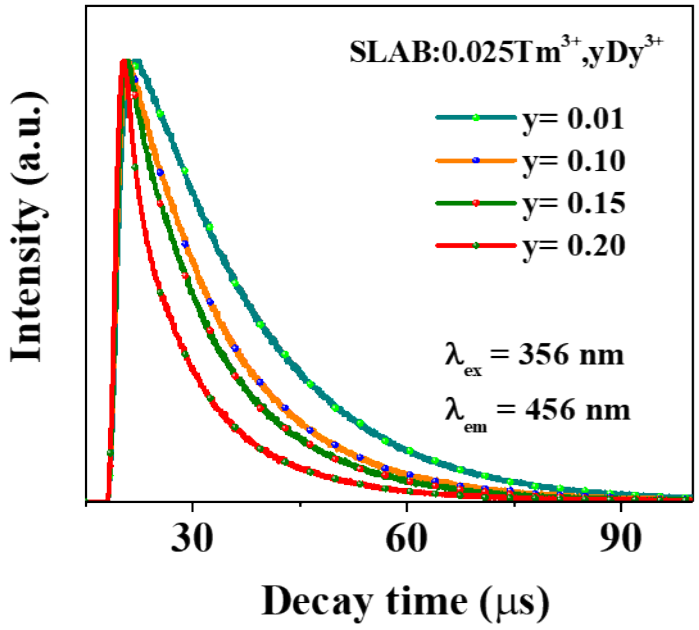


**Fig. S4.** Decay plots of the samples SLAB:0.025$Tm^{3+}$,y$Dy^{3+}$ (y=0.01, 0.1, 0.15 and 0.20).

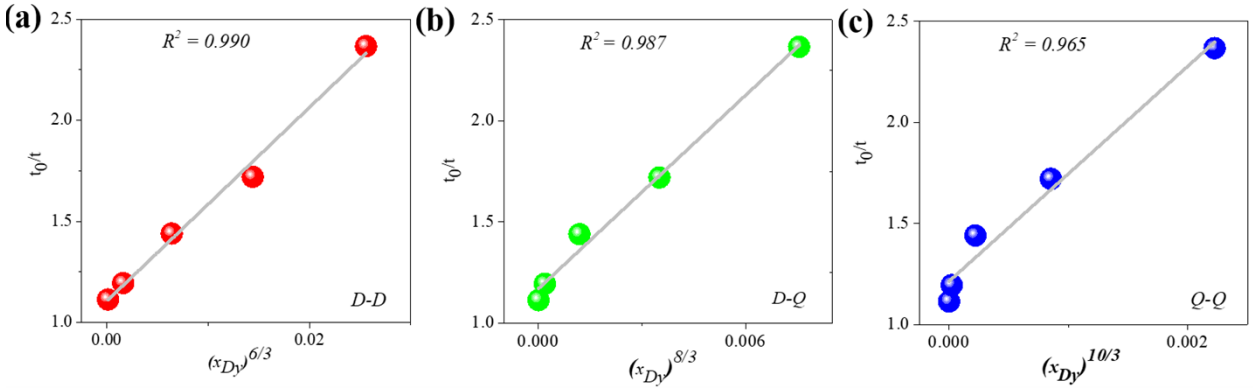


**Fig. S5.** The dependence of $\tau_0/\tau$ on the total content of $Tm^{3+}$ and $Dy^{3+}$ in SLAB.

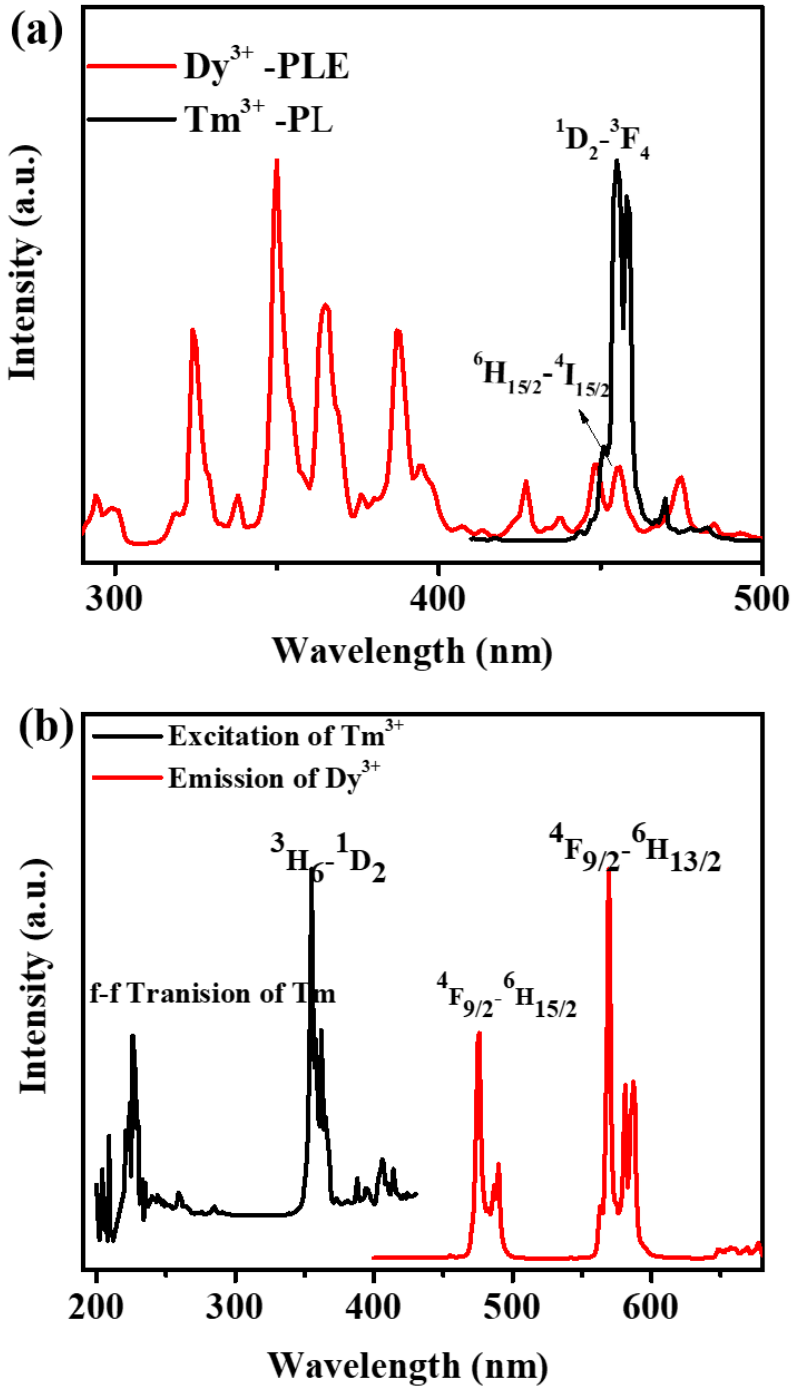


**Fig. S6.** The spectral overlap of $Dy^{3+}$ excitation and $Tm^{3+}$ emission in SLAB and of $Tm^{3+}$ excitation and $Dy^{3+}$ emission in SLAB.

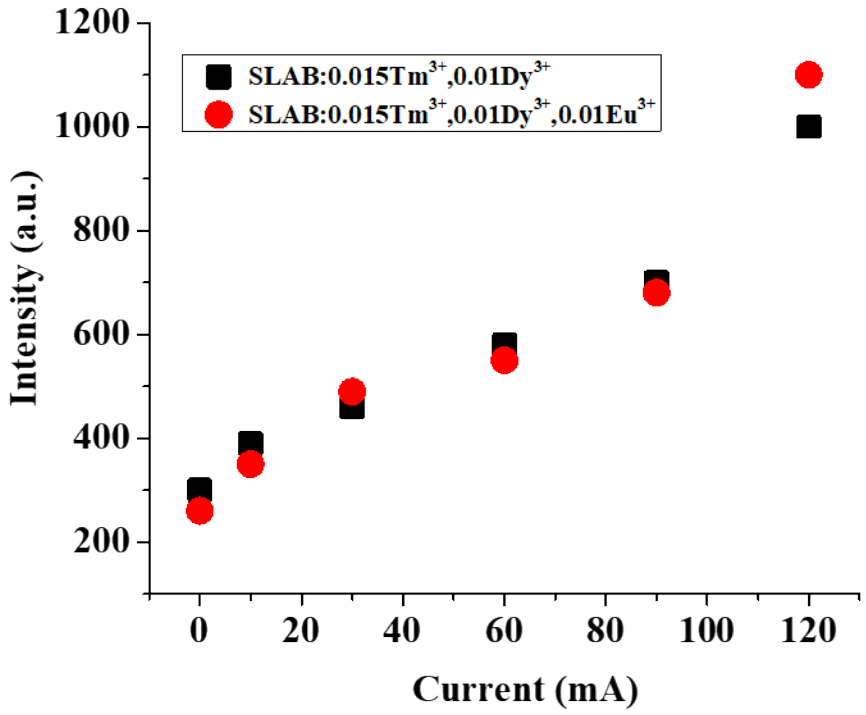


**Fig. S7**. CL intensities under different forwarding bias currents (0–120 mA).

The following formula converts the CIE 1931 x and y values into their corresponding Duv values.[1, 2]

1) Convert chromaticity coordinates from $(x, y)$ or $(u', v')$ to $(u, v)$, use the following formulas:

$$u = \frac{4x}{(-2x + 12y + 3)} \qquad \text{Or} \qquad u = u'$$

$$v = \frac{6y}{(-2x + 12y + 3)} \qquad v = \frac{2v'}{3}$$

2) Duv is obtained by

$$L_{FP} = \sqrt{(u - 0.292)^2 + (v - 0.24)^2}$$

$$a = \arccos\left(\frac{u - 0.292}{L_{FP}}\right)$$

$$L_{BB} = k_6 a^6 + k_5 a^5 + k_4 a^4 + k_3 a^3 + k_2 a^2 + k_1 a + k_0$$

$$D_{uv} = L_{FP} - L_{BB}$$

Where, $k_0$=-0.471106, $k_1$=1.925865, $k_2$=-2.4243787, $k_3$=1.5317403, $k_4$=-0.5179722, $k_5$=-0.08939440, and $k_6$=-0.00616793. The calculated value of $D_{uv}$ for SLAB:0.015$Tm^{3+}$,x$Dy^{3+}$ are listed in **Table S4**.


1. D. Baxter, M. Royer and K. Smet, *Leukos*, 2024, **20**, 55-66.
2. M. Royer, M. J. Murdoch, K. Smet, L. Whitehead, A. David, K. Houser, T. Esposito, J. Livingston and Y. Ohno, *Leukos*, 2023, **19**, 35-52.