Supporting Information

The influence of the dopant concentration on temperature dependent emission spectra in LiLa$_{1-x-y}$Eu$_x$Tb$_y$P$_4$O$_{12}$ nanocrystals: toward rational designing of highly-sensitive luminescent nanothermometer

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Figure S1. X-ray diffraction data for LiLa$_{1-x-y}$Eu$_x$Tb$_y$P$_4$O$_{12}$ nanocrystals

Figure S1. X-ray diffraction data for LiLa$_{1-x-y}$Eu$_x$Tb$_y$P$_4$O$_{12}$ nanocrystals
Figure S2. TEM images of LiLa$_{0.5}$Eu$_{0.1}$Tb$_{0.4}$P$_4$O$_{12}$ nanocrystals –a and b with grain size distribution –c.

Figure S3. The comparison of emission spectra of LiLa$_{1-x-y}$Eu$_x$Tb$_y$P$_4$O$_{12}$ for constant $x=0.1$ concentration of Eu$^{3+}$ ions-a; and for constant $x=0.1$ concentration of Tb$^{3+}$ ions-b.
Figure S4. Emission spectra of LiLa$_{0.89}$Eu$_{0.01}$Tb$_{0.1}$P$_4$O$_{12}$ nanocrystals measured at different temperatures.
Figure S5. Temperature evolution of Tb$^{3+}$ (a) and Eu$^{3+}$ (b) emission intensities in LiLa$_{1-x-y}$Eu$_x$Tb$_y$P$_4$O$_{12}$ nanocrystals for samples doped with constant $x=0.1$ Eu$^{3+}$ ions concentration and different Tb$^{3+}$ concentration; temperature evolution of Tb$^{3+}$ (c) and Eu$^{3+}$ (d) emission intensities respectively for samples doped with constant $x=0.1$ Tb$^{3+}$ ions concentration and different Eu$^{3+}$ concentration.

Energy transfer which can take place between Eu$^{3+}$ and Tb$^{3+}$ ions can be described by following rate equations:

\[
\frac{dn_0}{dt} = -\Phi n_0 + n_3 W_{30} + n_4 W_{40} + n_8 n_1 W^{10} - n_2 n_0 W^\text{CR4} \tag{S1}
\]

\[
\frac{dn_3}{dt} = n_3 W_{31} + n_4 W_{41} - n_8 n_1 W^{10} - n_1 W^{1\text{NR}} \tag{S2}
\]

\[
\frac{dn_2}{dt} = n_3 W_{32} + n_4 W_{42} + n_8 n_0 W^\text{CR4} - n_2 W^{2\text{NR}} \tag{S3}
\]

\[
\frac{dn_3}{dt} = -n_3 W^\text{ET83} W^{\text{ET83}} n_3 + n_4 n_0 W^\text{CR4} + n_3 n_5 W^{\text{CR5}} + W^\text{BET} W^\text{BET} n_8 - W^{3\text{NR}} n_3 + W^{4\text{NR}} n_4 \tag{S4}
\]

\[
\frac{dn_4}{dt} = \Phi n_0 - n_4 W^\text{CR4} - n_3 n_5 W^5 - n_4 W^{4\text{NR}} \tag{S5}
\]
\[
\frac{dn_5}{dt} = n_7 W_{71} - n_5 n_4 W^{55} + n_6 n_8 W^{11}
\]  \hspace{1cm} (S6)

\[
\frac{dn_6}{dt} = -n_6 n_8 W^{11} + n_3 W^{7NR} + W_{86} n_8 - W^{NR5}_6 n_6
\]  \hspace{1cm} (S7)

\[
\frac{dn_7}{dt} = -W^{7NR} n_7 + n_5 n_6 W^5 + W^{87}_6 n_6 + W^{7NR} n_7
\]  \hspace{1cm} (S8)

\[
\frac{dn_8}{dt} = -n_8 W_8 - n_5 n_6 W^{11} - n_6 n_7 W^{10} + W^{9NR} n_9 - n_8 W^{NR8}
\]  \hspace{1cm} (S9)

\[
\frac{dn_9}{dt} = -W^{NR9} n_9 + W^{10} n_9 n_1 - n_7 W^{ET\, 93} + n_3 W^{ET\, 93} + W^{NR10} n_{10}
\]  \hspace{1cm} (S10)

\[
\sum_i n_i = N
\]  \hspace{1cm} (S11)

\[
\frac{n_i}{N} = N_i
\]  \hspace{1cm} (S12)

where \(W^{NRi}\) represent the nonradiative decay rate of the \(i^{th}\)-state, \(W_{ij}\) represents the probability of radiative transition between \(i\) and \(j\) states, \(W^{ET}_{ij}\) represents probability of energy transfer between \(i\) and \(j\) state and \(BET\) is back (Eu\(^{3+}\)→Tb\(^{3+}\)) energy transfer probability. \(W^{CR10}\) represents probability of cross relaxation process represented as process 10 in Fig. 5 and \(n_i\) is the population of \(i^{th}\) state.