Supporting Information

Towards ultra-sensitive multimodal luminescent thermometers enabled by high crystal field strength of $Lu_2CaMg_2Ge_3O_{12}$:Yb^{3+}, Nd^{3+}, Er^{3+} phosphors

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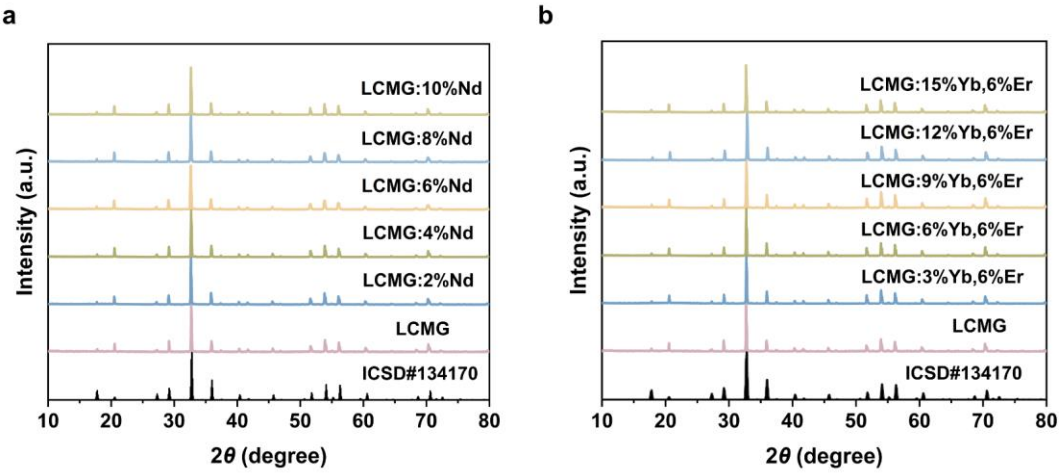

Fig. S1. XRD patterns of (a) LCMG: x%Nd^{3+} (x=2, 4, 6, 8, 10) and LCMG: x%Yb^{3+}, 6%Er^{3+} (x=3, 6, 9, 12, 15).

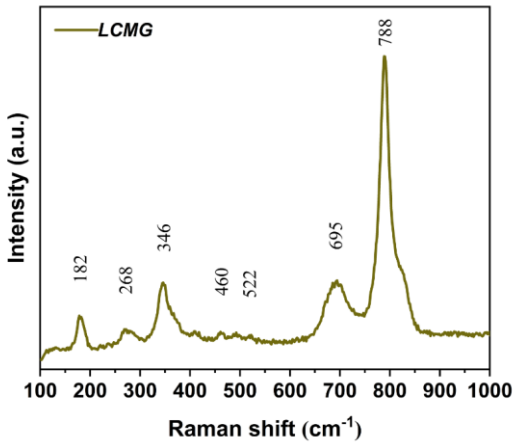

Fig. S2. Raman spectrum of the LCMG host.

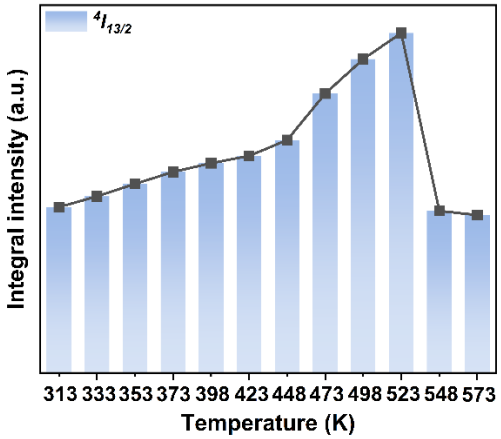

Fig. S3. The integrated intensity of $^4I_{13/2}$ emission in the LCMG:12%Yb^{3+},6Er^{3+}.

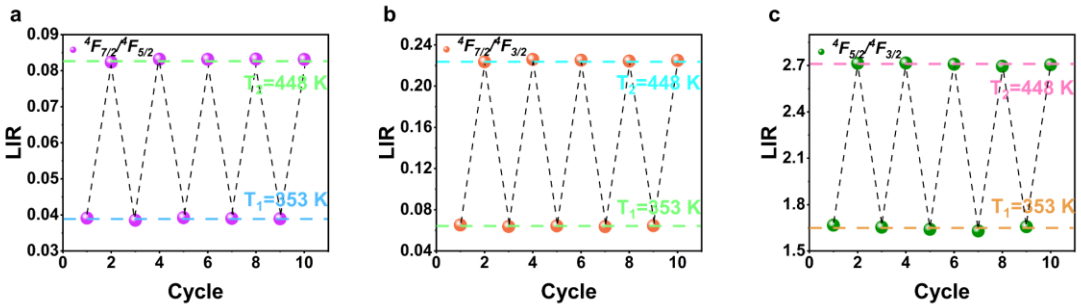

Fig. S4. The repeatability of LIR of LCMG: 6%Yb^{3+}, 6%Nd^{3+} phosphors.

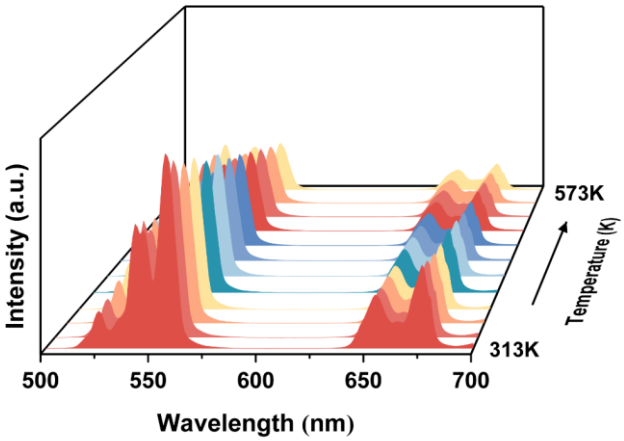

Fig. S5. Temperature-dependent spectra of LCMG:12 %Yb^{3+},6%Er^{3+} with the temperature range from 313 K to 573 K, excited by 980 nm laser.

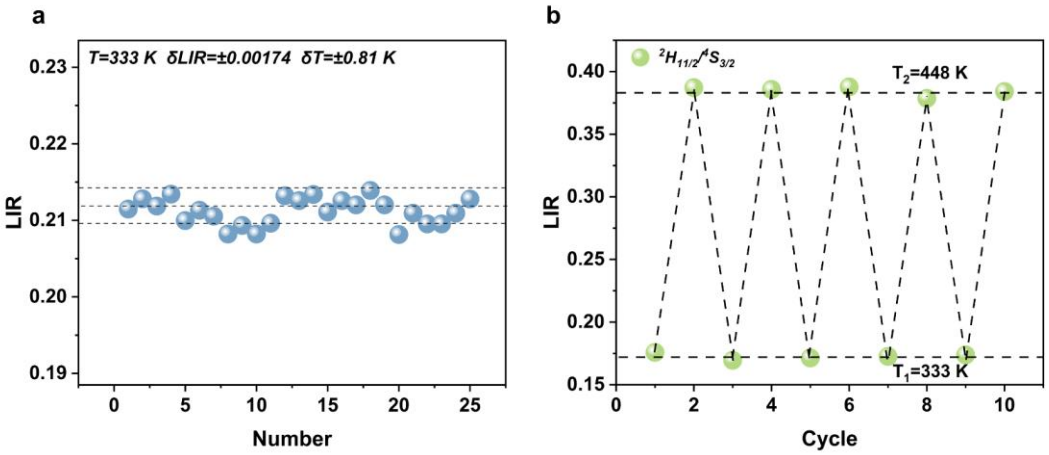

Fig. S6. (a) 25 measurements of LIR of LCMG: 12%Yb^{3+}, 6%Er^{3+} phosphors at 333 K. (b) The temperature-recycle measurements of LIR values of LCMG: 12%Yb^{3+}, 6%Er^{3+} phosphors.

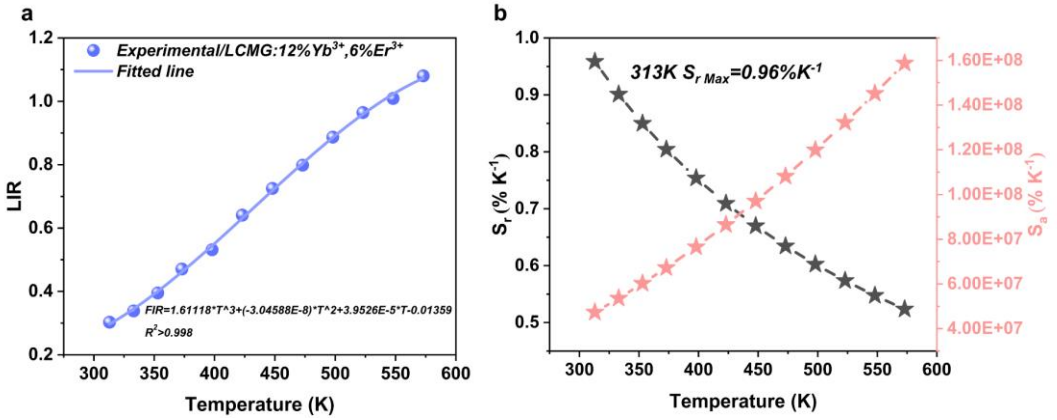

Fig. S7. (a) Temperature-dependent LIR between $^4S_{3/2}$ and $^4F_{9/2}$ non-TCLs. (b) The calculated relative temperature sensitivity (S_r) and the absolutely temperature sensitivity (S_a) of Yb-Er in the temperature ranges of 313–573 K.

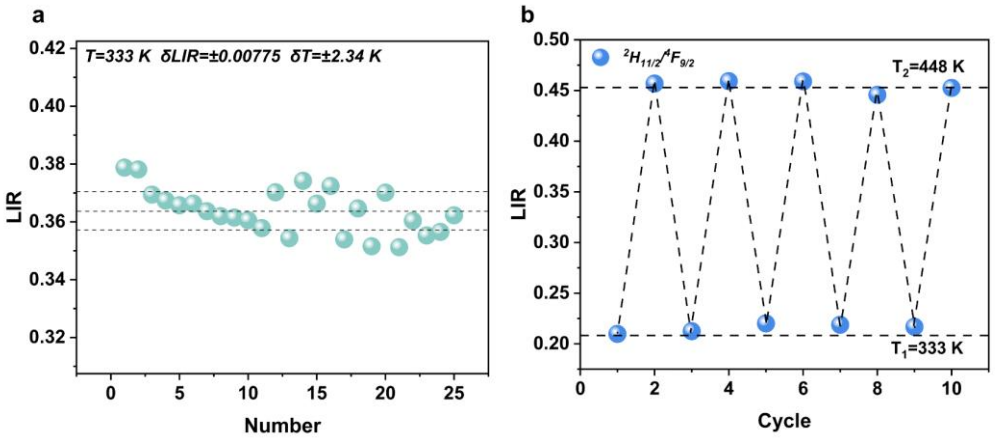

Fig. S8. (a)25 measurements of LIR of LCMG: 12%Yb^{3+}, 6%Er^{3+} phosphors at 333 K.(b) The temperature-recycle measurements of LIR values of LCMG: 12%Yb^{3+}, 6%Er^{3+} phosphors.

Table S1. The Ionic Radii of Lu^{3+} , Yb^{3+}, Nd^{3+}, Er^{3+}, Ca^{2+}, Mg^{2+} and Ge^{4+} at certain coordination number.

ion	coordination number	ionic radii (Å)
Lu^{3+}	8	0.977
Yb^{3+}	8	0.985
Nd^{3+}	8	1.109
Er^{3+}	8	1.004
Ca^{2+}	8	1.120
Mg^{2+}	6	0.720
Ge^{4+}	4	0.390

Table S2. Calculated Environmental Factors and Bond Parameters of LCMG Crystals.

bond type	E_g	Ks	C^{μ} (eV)	f_c^{μ}	α_b^{μ} (Å^3)	β	v_b^{μ}
Lu-O	19.9488	2.3297	19.4618	0.0482	0.2835	0.1640	3.8689
Ca-O	16.8773	2.1734	15.4803	0.0729	0.2579	0.1640	3.9132
Mg-O	19.7923	2.5450	18.3219	0.1431	0.1890	0.1640	2.0238
Ge-O	20.6571	3.1741	18.5793	0.1910	0.2709	0.1640	1.6134

In Table 1, n_D represents refractivity; f_c denotes covalency; E_h and f_i denote the average homopolar energy and the average ionicity of chemical bond between the lanthanide ion and ligands; Z and N represent the average presented charge and the nearest total coordination number of ligands; α_p denotes the polarizability of the immediate environment around Er^{3+} ions.

In Table S2, E_g is the average energy gap between the bonding molecular orbital and the antibonding molecular orbital of the μ-type bond; f_c^{μ} represents the covalency of any μ-type bond; C^{μ} denotes the heteropolar energy; α_b^{μ} denotes the polarizability of the chemical bond volume; v_b^{μ} is the bond volume of any μ-type bond.