Supporting Information

Highly Efficient Red/Orange-red Emitting Eu^{3+} and Sm^{3+}/Eu^{3+} Co-doped Phosphors with their Versatile Applications

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Characterization

Data of Powder X-ray diffraction were obtained from the Rigaku ULTIMA IV, Japan (radiative source: Co-Kα1, producing the X-ray). Rietveld refinement for the composition was done by JANA 2006 taking the step width as 0.01. Diamond software was utilized for the representation of the formed crystal structure. The Scanning Electron Microscopy (SEM) images were obtained from JEOL JSM 6480LV. The FT-IR (Fourier transform infrared spectroscopy) was recorded by PerkinElmer Spectrum Version 10.4.00 for the range 400–4000 cm^{-1}. The data of excitation and emission spectra of photoluminescence, lifetime analysis, and quantum yield were recorded by Edinburg Spectrofluorometer FS–5 instrument, having a pulsed xenon lamp as the excitation source and with the SC – 10 modules and SC – 30 integrating sphere modules. The signals were acquired with a photomultiplier. A temperature controller equipped spectrometer (Edinburgh FS5) was used for the temperature-dependent photoluminescence data. CIE color coordinates were determined from the emission spectra of the synthesized phosphors via MATLAB software. All the characterization procedures were performed at room temperature.

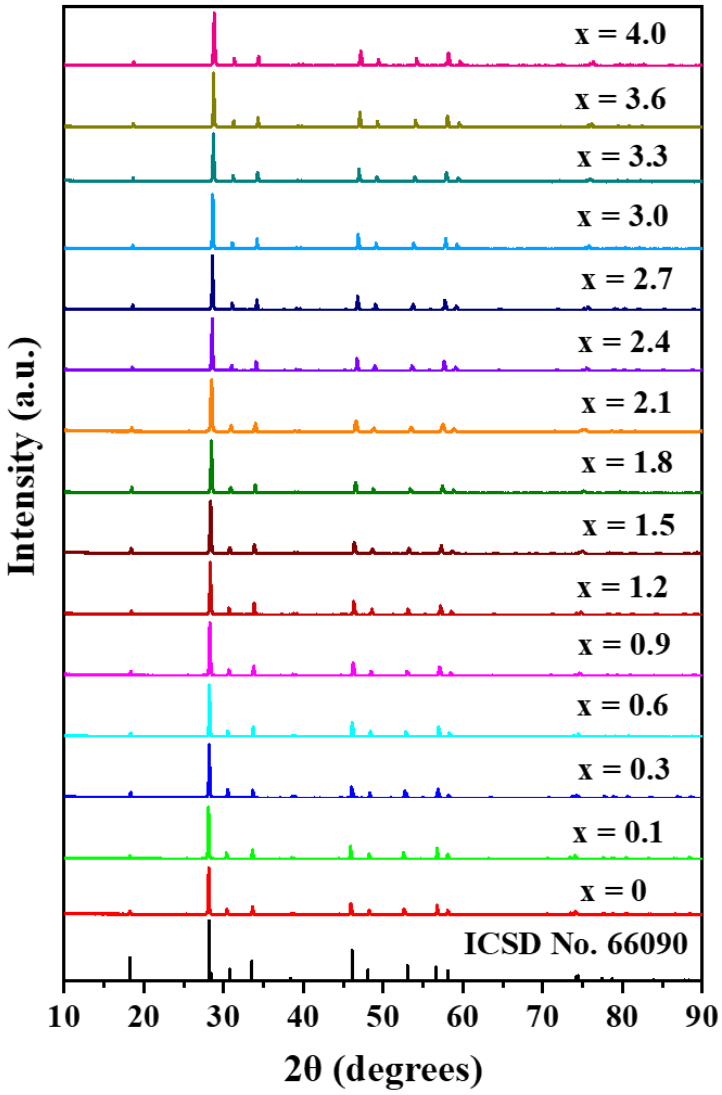


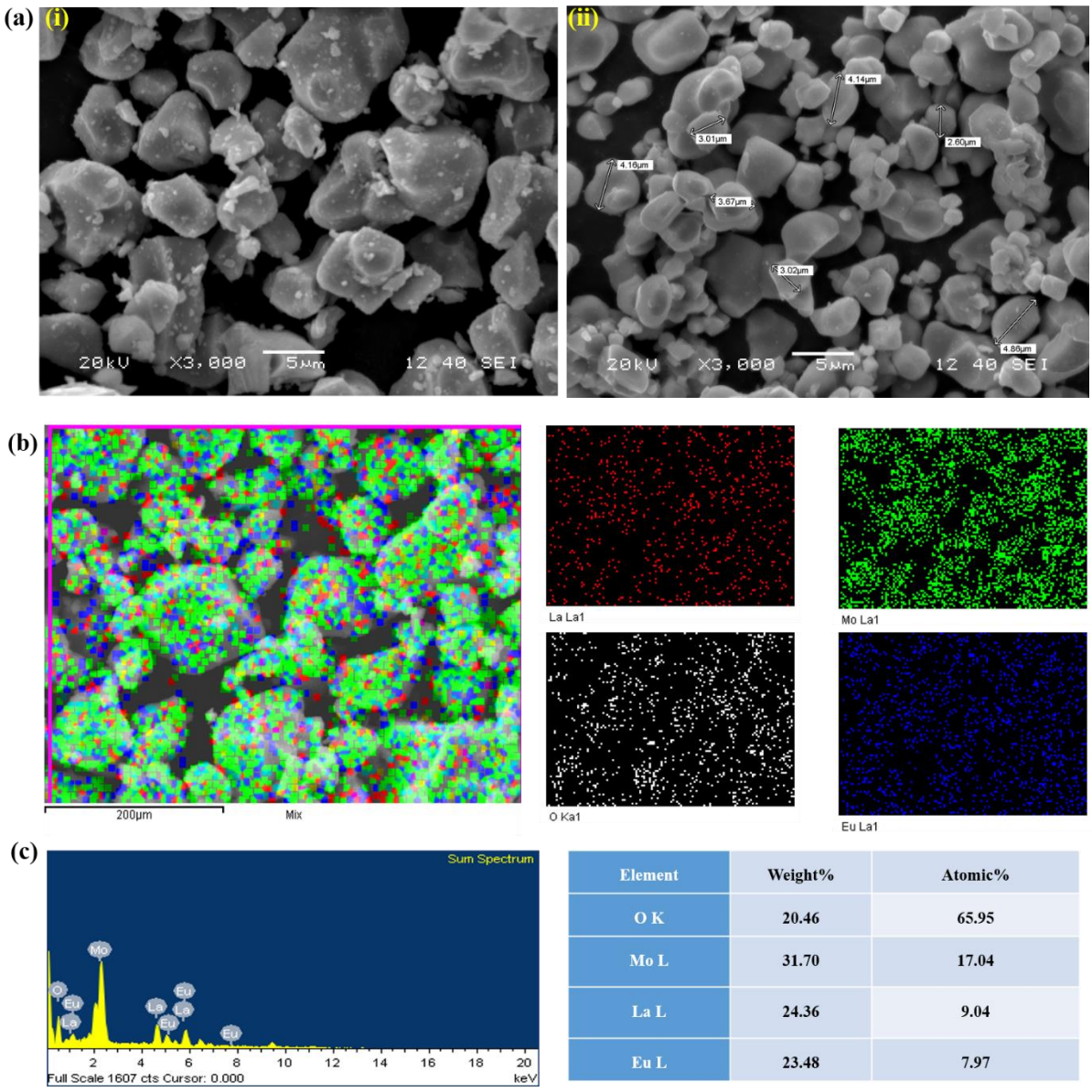
Fig. S1. Powder XRD pattern of $Li_2La_{4-x}(MoO_4)_7$:xEu^{3+} (where, x = 0–4) phosphors.

Table ST1: Atomic coordinates and occupancy parameters obtained from the Rietveld refinement of PXRD data of $Li_2La_4(MoO_4)_7$.

$Li_2La_4(MoO_4)_7$	Atomic coordinates			Occ.	Wyck.	Site	U [Å]
Atoms	x	y	z				
Li1	0.00000	0.75000	0.87500	0.23232	4a	–4m	0.0085
La1	0.00000	0.75000	0.87500	0.45235	4a	–4m	0.0085
Mo1	0.50000	0.75000	0.12500	1.00000	4b	–4m	0.0085
O1	0.75500	0.52373	0.02493	1.00000	16f	1m	0.0085

Table ST2: Lattice parameters of $Li_2La_{4-x}(MoO_4)_7$:xEu^{3+} phosphors.

Conc. of Eu^{3+} in terms of x	**a (Å)**	**b (Å)**	**V (Å3)**
0	5.3306	11.7490	334.1625
0.1	5.3301	11.7428	333.6125
0.3	5.324	11.7216	332.2484
0.6	5.3148	11.7064	330.7618
0.9	5.3056	11.6692	328.4808
1.2	5.2964	11.6468	326.7143
1.5	5.2934	11.6248	325.7278
1.8	5.2752	11.5808	322.2674
2.1	5.2722	11.5588	321.2894
2.4	5.2602	11.5296	319.0206
2.7	5.2482	11.5152	317.1701
3	5.2452	11.5008	316.4114
3.3	5.2334	11.4648	314.0033
3.6	5.2244	11.4432	312.3347
4	5.2156	11.4148	310.5109



Element	Weight%	Atomic%
O K	20.46	65.95
Mo L	31.70	17.04
La L	24.36	9.04
Eu L	23.48	7.97

Fig. S2. (a) SEM images of LLM and LLM:Eu^{3+} phosphor. (b) Elemental analysis and (c) EDX spectra of LLM:Eu^{3+} phosphor.

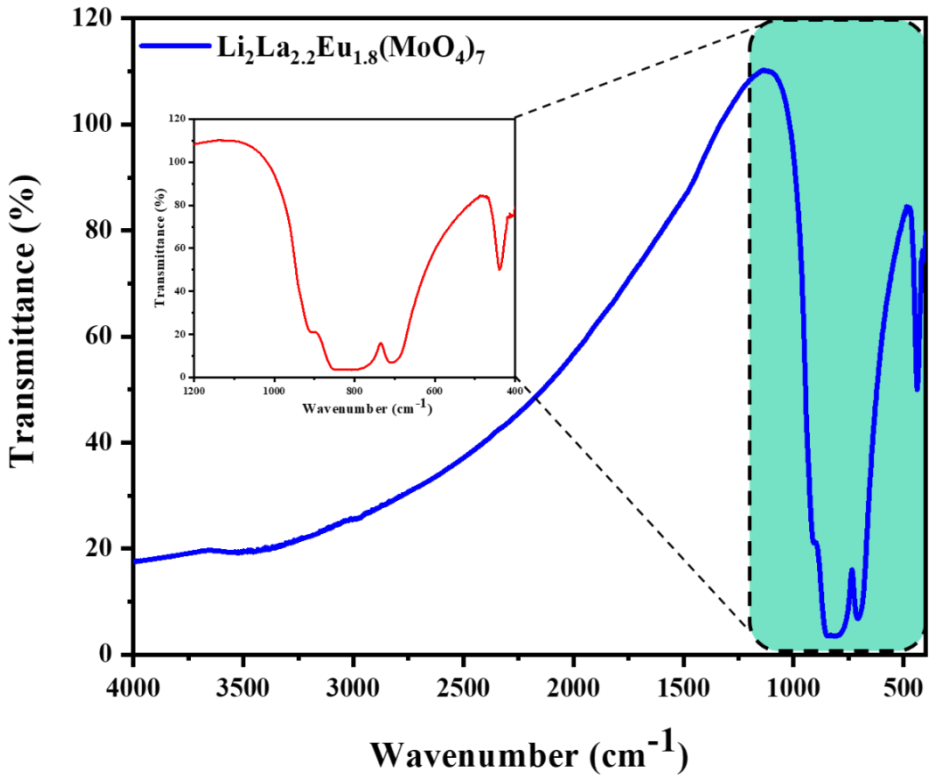


Fig. S3. FT-IR spectrum of $Li_2La_{2.2}(MoO_4)_7$:1.8Eu^{3+}.

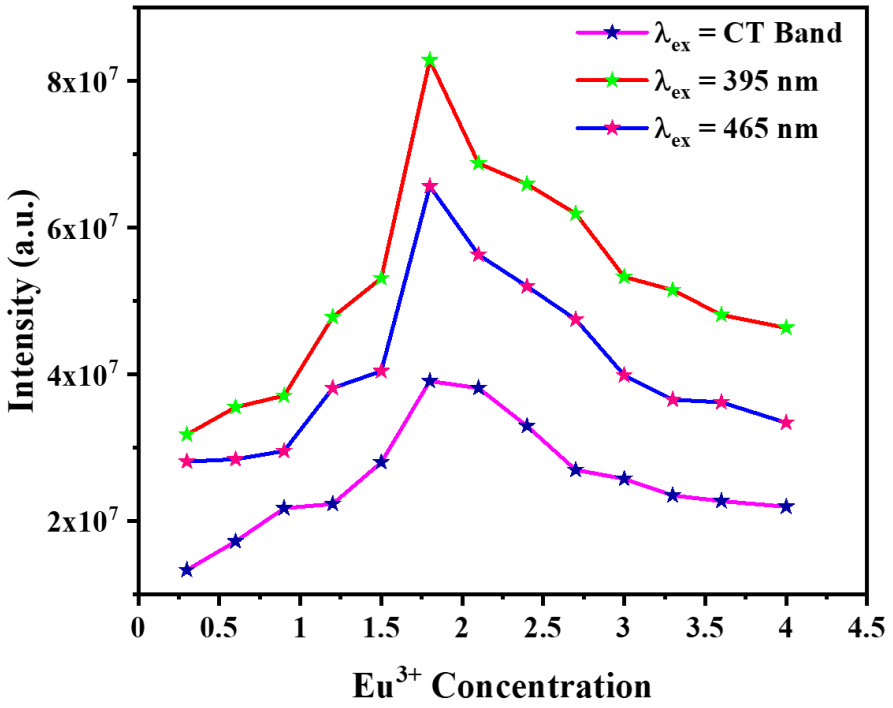


Fig. S4. PL excitation and emission spectrum at (b) 395 nm, (c) CT band, and (d) 465 nm excitation wavelength.

Table ST3: Asymmetric ratio and FWHM of $Li_2La_4(MoO_4)_7:Eu^{3+}$ phosphors.

Eu^{3+} Conc.	CT band		395 nm		465 nm	
	AR	FWHM	AR	FWHM	AR	FWHM
0.3	16.9748	5.12	17.5365	4.44	18.4492	5.12
0.6	19.1819	5.12	18.3980	5.33	18.4946	5.12
0.9	18.7586	5.12	18.7632	5.33	18.4168	5.12
1.2	17.3740	5.12	18.8750	5.33	18.9819	5.12
1.5	18.2247	5.12	18.9465	4.72	18.7856	5.12
1.8	19.9357	5.12	19.4556	5.12	19.2271	5.12
2.1	18.2352	5.12	17.2709	5.12	19.1124	5.12
2.4	15.7418	5.12	18.0276	5.12	18.4169	5.12
2.7	17.6539	5.12	18.5884	5.12	18.3851	5.12
3.0	18.6983	5.12	18.5876	4.44	18.2894	5.12
3.3	18.8113	5.12	19.0578	4.44	17.5911	5.12
3.6	15.2569	5.12	18.4542	4.44	18.2122	5.12
4.0	17.0981	5.12	17.8655	4.72	18.1464	5.12

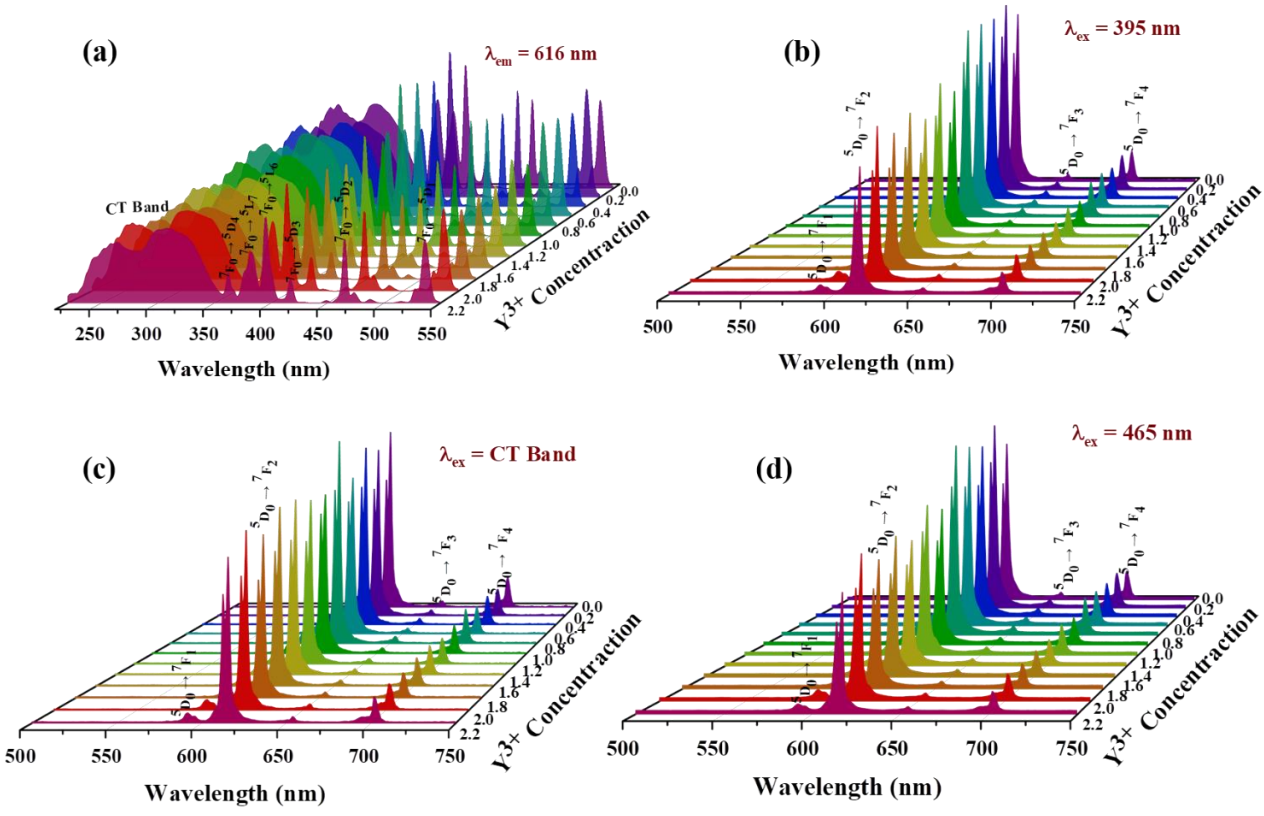


Fig. S5. PL excitation and emission spectrum at (b) 395 nm, (c) CT band, and (d) 465 nm excitation wavelength.

Table ST4: CIE coordinates and color purity of $Li_2La_4(MoO_4)_7:Eu^{3+}$ phosphors.

Conc. of Eu^{3+}	CT Band			395 nm			465 nm		
	CIE Coordinates		CP (%)	CIE Coordinates		CP (%)	CIE Coordinates		CP (%)
	x	y		x	y		x	y	
0.3	0.6581	0.3405	94.31	0.6602	0.3391	95.79	0.6594	0.3397	94.64
0.6	0.663	0.3361	95.55	0.6639	0.3355	96.22	0.6634	0.3359	95.66
0.9	0.6651	0.3342	96.09	0.6656	0.3339	96.69	0.6647	0.3347	95.99
1.2	0.6657	0.3336	96.24	0.6674	0.3322	96.87	0.6667	0.3327	96.50
1.5	0.6668	0.3326	96.53	0.6681	0.3315	97.02	0.6675	0.332	96.71
1.8	0.6682	0.3312	96.89	0.6697	0.3301	97.28	0.6689	0.3307	97.07
2.1	0.6679	0.3315	96.81	0.6693	0.3303	97.10	0.668	0.3316	96.84
2.4	0.668	0.3314	96.84	0.669	0.3307	97.12	0.6683	0.3313	96.92
2.7	0.6677	0.3317	96.76	0.6691	0.3305	97.23	0.6687	0.3309	97.02
3.0	0.6677	0.3316	96.76	0.6695	0.3302	97.18	0.6689	0.3307	97.07
3.3	0.6682	0.3312	96.89	0.6697	0.3299	97.25	0.6687	0.3308	97.02
3.6	0.6669	0.3325	96.55	0.6696	0.33	97.23	0.6688	0.3307	97.05
4.0	0.6675	0.3318	96.71	0.6695	0.3301	94.85	0.6687	0.3309	97.02

Table ST5: CIE coordinates and color purity of $Li_2La_4(MoO_4)_{7-y}(WO_4)_y:Eu^{3+}$ phosphors.

Conc. of WO_4^{2-}	CT Band			395 nm			465 nm		
	CIE Coordinates		CP (%)	CIE Coordinates		CP (%)	CIE Coordinates		CP (%)
	x	y		x	y		x	y	
1	0.6668	0.3326	96.58	0.6679	0.3317	96.81	0.6669	0.3326	96.56
2	0.6667	0.3327	96.50	0.6677	0.3319	96.76	0.667	0.3325	96.58
3	0.6668	0.3326	96.58	0.6679	0.3317	96.81	0.6672	0.3323	96.63
4	0.667	0.3324	96.53	0.6678	0.3318	96.79	0.6673	0.3323	96.66
5	0.6656	0.3337	96.22	0.6667	0.3329	96.51	0.6658	0.3337	96.27
6	0.6656	0.3338	96.22	0.6671	0.3325	96.61	0.6665	0.333	96.45
7	0.6634	0.3358	95.66	0.667	0.3326	96.58	0.6663	0.3332	96.40

Table ST6: Comparison study of IQE with some reported literature.

S. No.	Phosphor composition	IQE (%)	Ref.
1	$La_2Mo_2O_9:Eu^{3+}$	64.5	[1]
2	$Na_2Gd(PO_4)(MoO_4):0.5Eu^{3+}$	54.4	[2]
3	$Cs_2Ba(MoO_4):Eu^{3+}$	48.9	[3]
4	$Na_2Lu(MoO_4)(PO_4):Eu^{3+}$	73.1	[4]
5	$Li_2La_4(MoO_4)_7:1.8Eu^{3+}$ $Li_2La_{2.2}Eu_{1.8}(MoO_4)_4(WO_4)_3$	89.6 92.54	This work

Table ST7: Comparison study of thermal stability and E_a with some reported literature.

S. No.	Phosphor Composition	Thermal stability at 423 K	Activation energy (E_a)	Ref.
1	$K_2Gd(WO_4)(PO_4):Eu^{3+}$	72%	0.19 eV	[5]
2	$Na_2Lu(MoO_4)(PO_4):Eu^{3+}$	64.5%	0.2 eV	[4]
3	$Cs_2Ba(MoO_4)_2:Eu^{3+}$	61%	0.26 eV	[3]
4	$NaSrY(MoO_4)_3:Eu^{3+}$	64.6%	0.263 eV	[6]
5	$Li_2La_4(MoO_4)_7:1.8Eu^{3+}$ $Li_2La_{2.2}Eu_{1.8}(MoO_4)_4(WO_4)_3$	81.75% 86.12%	0.213 eV 0.21 eV	This work

Table ST8: Judd-Ofelt Parameters of $Li_2La_4(MoO_4)_7:Eu^{3+}$ Phosphor at λ_{ex} = 395 nm.

Concentration of Eu^{3+}	Judd-Ofelt Parameters		A_{0-1} in S^{-1}	A_{0-2} in S^{-1}	A_{0-4} in S^{-1}
	Ω_2 (10^{-19} cm^2)	Ω_4 (10^{-20} cm^2)			
0.3	1.1726	4.5228	50	961.4860	180.0934
0.6	1.1755	4.4456	50	963.8474	177.0196
0.9	1.1686	4.8098	50	958.1737	191.5189
1.2	1.2044	4.8713	50	987.5752	193.9663
1.5	1.1920	5.0897	50	977.3615	202.6626
1.8	1.1686	4.7862	50	958.1775	190.5779
2.1	1.2127	5.4085	50	994.3654	215.3592
2.4	1.2200	5.1153	50	1000.3321	203.6833
2.7	1.1666	4.9884	50	956.5256	198.6330
3.0	1.1605	5.0866	50	951.5450	202.5417
3.3	1.11623	5.0769	50	915.2130	202.1545
3.6	1.15564	4.9316	50	947.5301	196.3692
4.0	1.15146	4.8385	50	944.1038	192.6621

Table ST9: Judd-Ofelt Parameters of $Li_2La_4(MoO_4)_7:Eu^{3+}$ Phosphor at λ_{ex} = 465 nm.

Concentration of Eu^{3+}	Judd-Ofelt Parameters				
	Ω_2 (10^{-19} cm^2)	Ω_4 (10^{-20} cm^2)	A_{0-1} in S^{-1}	A_{0-2} in S^{-1}	A_{0-4} in S^{-1}
0.3	1.1146	4.1889	50	913.9206	167.5102
0.6	1.2345	4.6660	50	1012.2204	185.7928
0.9	1.1906	4.8225	50	976.1977	192.0251
1.2	1.1977	4.8547	50	982.0146	193.3081
1.5	1.2022	4.8243	50	985.7312	192.0974
1.8	1.1674	4.8040	50	957.1955	191.2896
2.1	1.0959	4.7989	50	898.5549	191.0871
2.4	1.1439	4.7814	50	937.9260	190.3892
2.7	1.1795	4.9813	50	967.1013	198.3480
3.0	1.1794	4.8991	50	967.0602	195.0748
3.3	1.2093	5.0847	50	991.5254	202.4647
3.6	1.1709	4.9845	50	960.1174	198.4758
4.0	1.1336	4.6860	50	929.4934	186.5913

Table ST10: Judd–Ofelt Parameters of $Li_2La_4(MoO_4)_7:Eu^{3+}$ Phosphor at λ_{ex} = CT band.

Concentration of Eu^{3+}	Judd-Ofelt Parameters				
	Ω_2 (10^{-19} cm^2)	Ω_4 (10^{-20} cm^2)	A_{0-1} in S^{-1}	A_{0-2} in S^{-1}	A_{0-4} in S^{-1}
0.3	1.0771	3.8569	50	883.1483	153.5751
0.6	1.2171	4.5887	50	997.9782	182.7152
0.9	1.2650	5.0604	50	1037.1952	201.4964
1.2	1.1024	4.1129	50	903.9180	163.7705
1.5	1.1564	4.5046	50	948.1799	179.3684
1.8	1.1903	4.8220	50	975.9579	192.0066
2.1	1.1571	4.6519	50	948.7238	185.2341
2.4	9.9888	4.2720	50	819.0003	170.1042
2.7	1.1202	4.4633	50	918.4799	177.7244
3.0	1.1864	4.5978	50	972.8176	183.0766
3.3	1.1936	5.0131	50	978.7005	199.6148
3.6	9.6811	4.2539	50	793.7744	169.3851
4.0	1.0849	4.6706	50	889.5672	185.9786

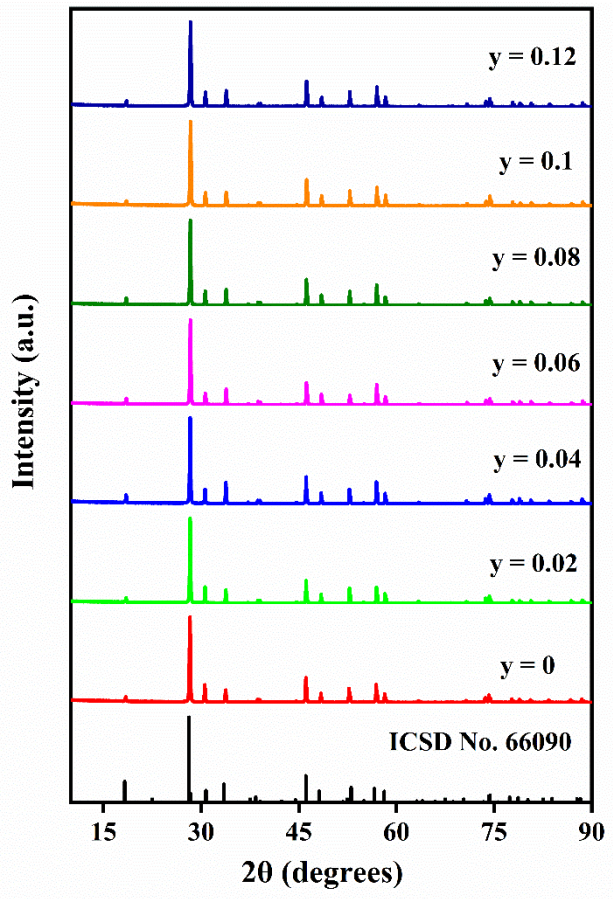


Fig. S6. Powder XRD pattern of $Li_2La_{3.9-y}(MoO_4)_7$:0.1Sm^{3+},yEu^{3+} (where, y = 0 – 0.12) phosphors.

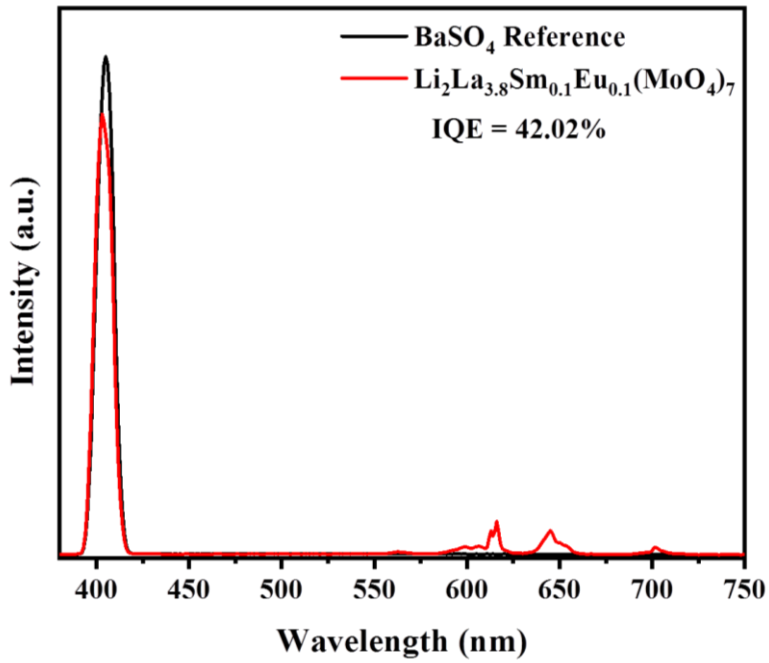


Fig. S7. Internal quantum efficiency of $Li_2La_{3.8}Sm_{0.1}Eu_{0.1}(MoO_4)_7$.

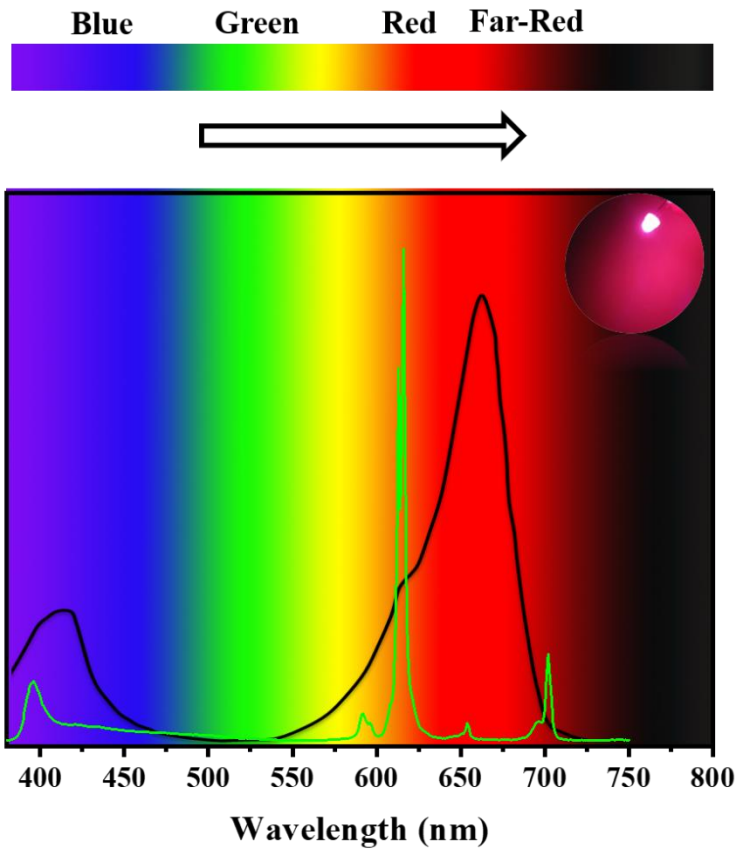


Fig. S8. EL spectrum of red LED with phytochrome P_R absorption spectrum.

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