Supporting Information

Study of multimodal light emissions from Pr^{3+}/Yb^{3+} doped $NaLa(MoO_4)_2$ phosphors for optoelectronic devices and plant-growth applications

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Tables

Table S1. Rietveld refined lattice parameters and unit cell volume for $NaLa_{1-x}Pr_x(MoO_4)_2$ ($0.00 \leq x \leq 0.11$) compounds.

Compounds	Lattice parameters (Å)		Cell volume (Å^3)
	a	*c*	
$NaLa(MoO_4)_2$	5.347(5)	11.753(1)	336.08(8)
$NaLa_{0.99}Pr_{0.01}(MoO_4)_2$	5.345(6)	11.745(8)	335.63(8)
$NaLa_{0.97}Pr_{0.03}(MoO_4)_2$	5.344(2)	11.741(3)	335.33(4)
$NaLa_{0.95}Pr_{0.05}(MoO_4)_2$	5.343(1)	11.738(5)	335.10(7)
$NaLa_{0.93}Pr_{0.07}(MoO_4)_2$	5.341(5)	11.735(7)	334.83(7)
$NaLa_{0.91}Pr_{0.09}(MoO_4)_2$	5.339(7)	11.734(8)	334.58(8)
$NaLa_{0.89}Pr_{0.11}(MoO_4)_2$	5.339(6)	11.735(5)	334.66(4)

Table S2. Rietveld refined structural parameters for $NaLa_{0.97}Pr_{0.03}(MoO_4)_2$ compounds.

Atoms	Oxidation State	Wyckoff Notation	Positional parameters			B_{iso}	Occupancy
			x	*y*	*z*		
Na	+1	4b	0.0000	0.2500	0.6250	0.500	1
La/Pr	+3	4b	0.0000	0.2500	0.6250	0.500	0.97/0.03
Mo	+6	4a	0.0000	0.2500	0.1250	0.500	2
O	-2	16f	0.7674(7)	0.1122(4)	0.0426(2)	0.500	8

Crystal system = Tetragonal, Space group = *I 41/a* (88),

Lattice parameters, *a* = 5.344(2) Å, *c* = 11.741(3) Å, Unit cell volume = 335.33(4) Å^3,

$R_{Factors}$; R_p = 3.06, R_{wp} = 4.11, Rexp: 2.33, χ^2= 3.11, R_{Bragg} = 6.90, R_F = 6.99.

Table S3. Rietveld refined structural parameters for $NaLa_{0.94}Pr_{0.03}Yb_{0.03}(MoO_4)_2$ compounds.

Atoms	Oxidation State	Wyckoff Notation	Positional parameters			B_{iso}	Occupancy
			x	*y*	*z*		
Na	+1	4b	0.0000	0.2500	0.6250	0.500	1
La/Pr/Yb	+3	4b	0.0000	0.2500	0.6250	0.500	0.94/0.03/0.03
Mo	+6	4a	0.0000	0.2500	0.1250	0.500	2
O	-2	16f	0.7749(3)	0.1154(7)	0.0427(8)	0.500	8

Crystal system = Tetragonal, Space group = *I 41/a* (88),

Lattice parameters, a = 5.340(9) Å, c = 11.733(4) Å, Unit cell volume = 334.71(2) Å^3,

$R_{Factors}$; R_p = 4.61, R_{wp} = 5.98, Rexp: 4.16, χ^2= 2.07, R_{Bragg} = 3.77, R_F = 7.03.

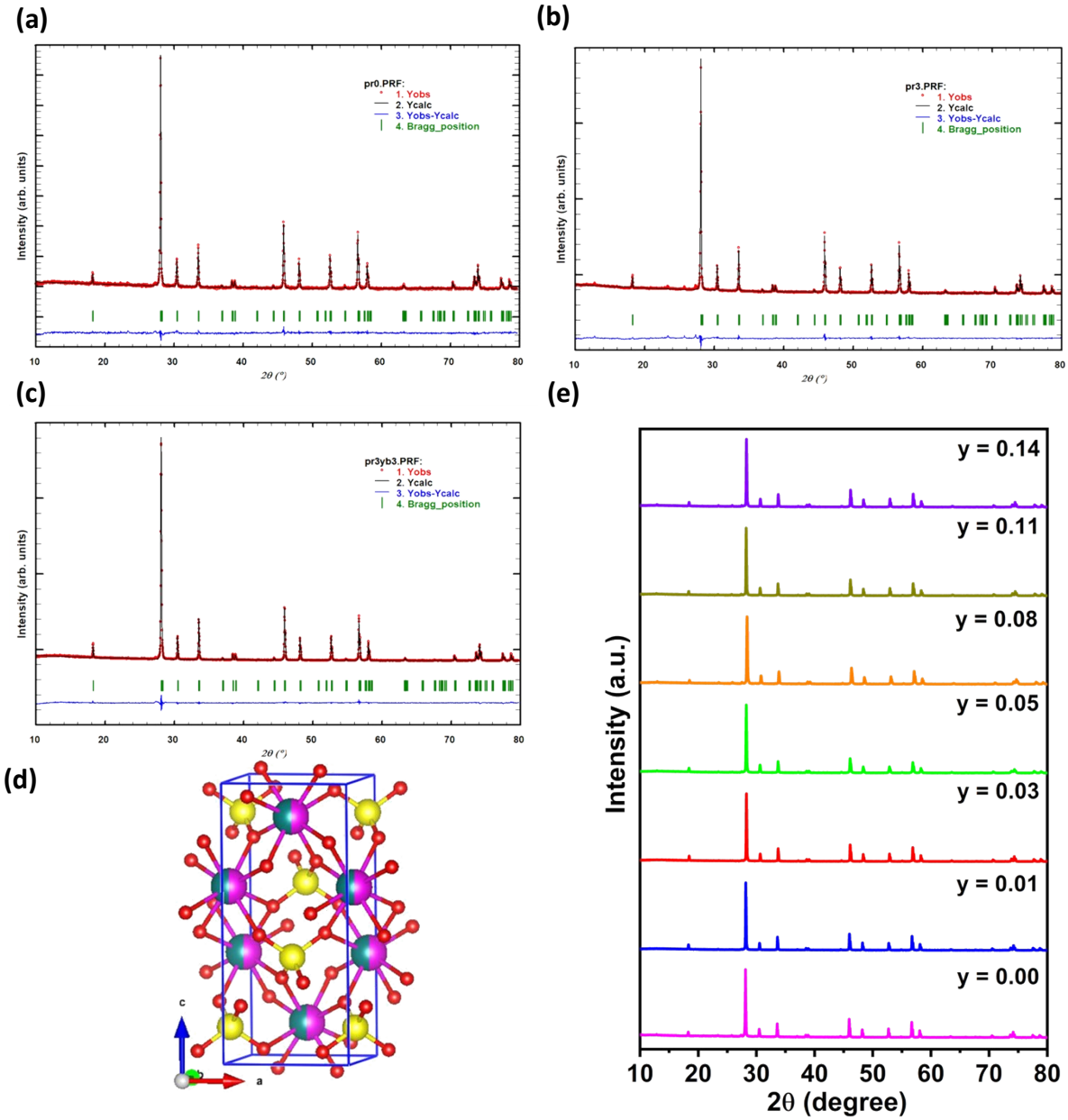

Figure S1. Rietveld plot of (a) $NaLa(MoO_4)_2$, (b) $NaLa_{0.97}Pr_{0.03}(MoO_4)_2$ and (c) $NaLa_{0.94}Pr_{0.03}Yb_{0.03}(MoO_4)_2$, (d) crystal structure of $NaLa_{0.97}Pr_{0.03}(MoO_4)_2$ and (e) XRD patterns of $NaLa_{0.97-y}Pr_{0.03}Yb_y(MoO_4)_2$ $(0.00 \leq x \leq 0.14)$ phosphors.

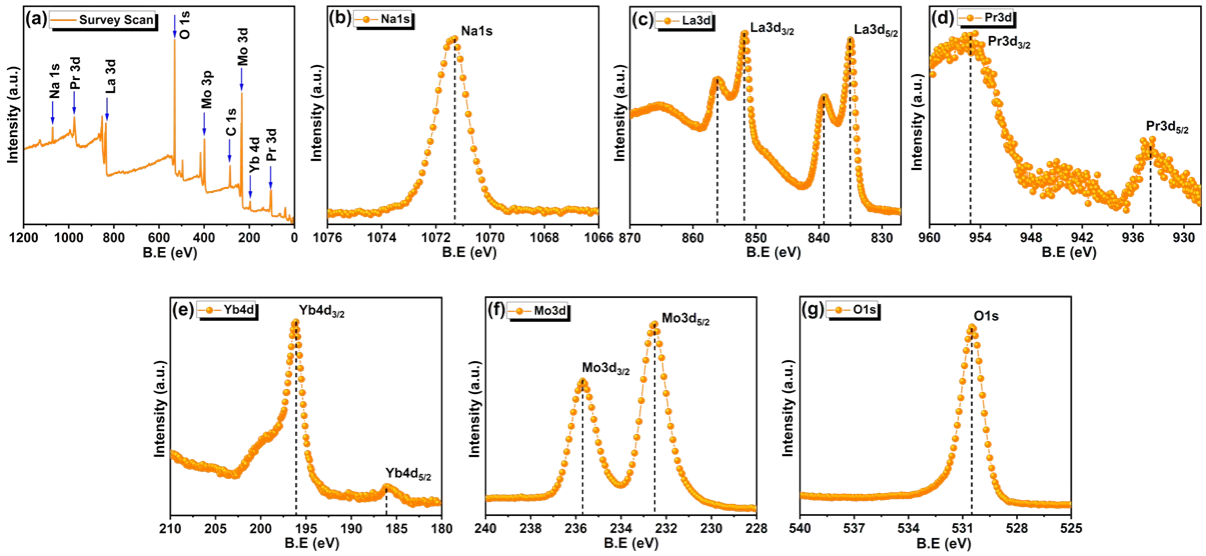

Figure S2. High-resolution XPS spectra of $NaLa_{0.92}Pr_{0.03}Yb_{0.05}(MoO_4)_2$: (a) XPS scan Survey (b) Na 1s spectra (c) La 3d spectra (d) Pr 3d, (e) Yb 4d, (f) Mo 3d spectra and (g) O 1s spectra.

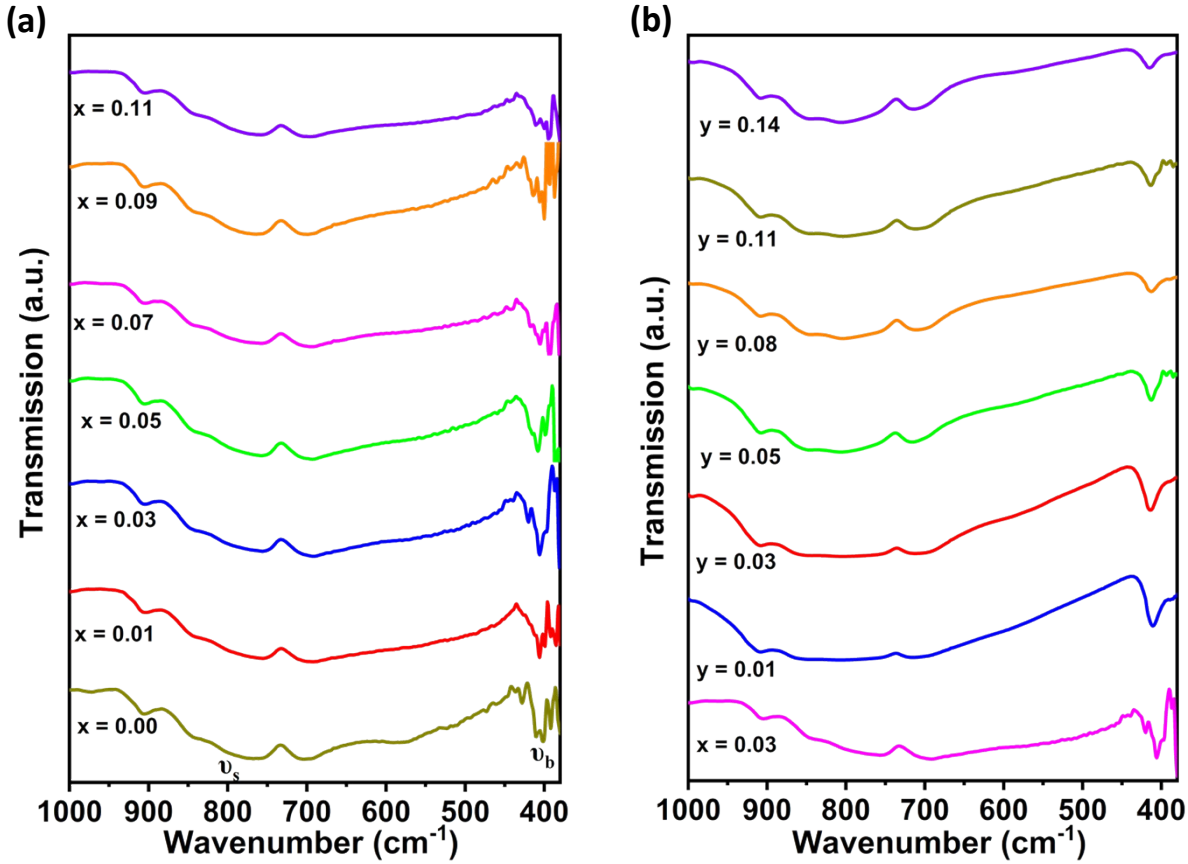

Figure S3. FTIR spectra of $NaLa_{1-x}Pr_x(MoO_4)_2$ and $NaLa_{0.97-y}Pr_{0.03}Yb_y(MoO_4)_2$ phosphors.

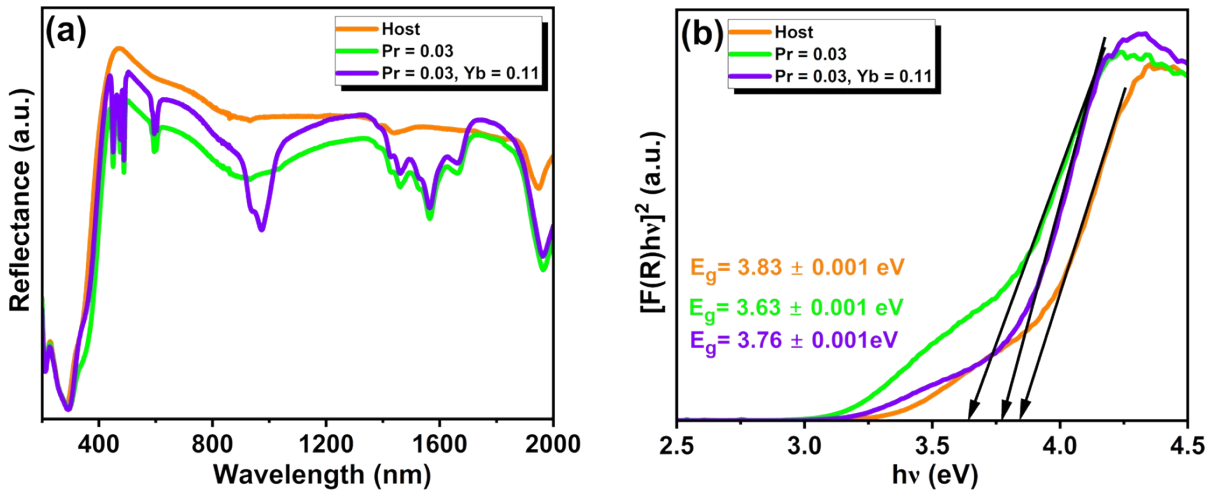

Figure S4. (a) Diffusion reflectance spectra of pure, Pr^{3+} doped and Pr^{3+}/Yb^{3+} doped NLMO and (b) Kubelka- Monk plot of Pr^{3+} doped and Pr^{3+}/Yb^{3+} doped NLMO.

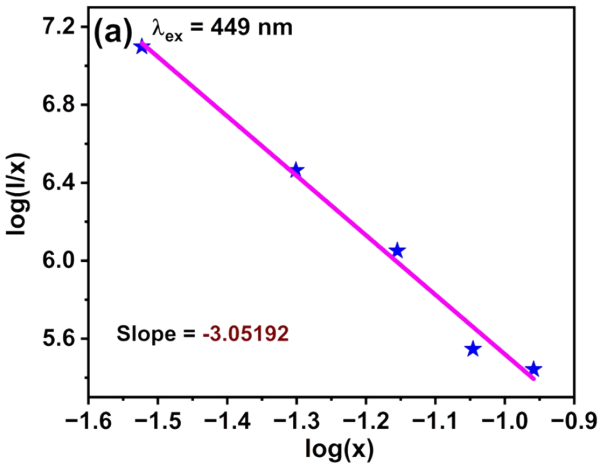

Figure S5. log(I/x) Vs log(x) plot of $NaLa_{0.97}Pr_{0.03}(MoO_4)_2$ ($0.01 \leq x \leq 0.11$).

Table S4. Variations of decay time (**τ**), energy transfer efficiency (η_{ETE}), and quantum cutting efficiency (η_{QE}) in Pr^{3+}/Yb^{3+} codoped NLMO samples on fixing the amount of Pr^{3+} and varying the amount of Yb^{3+} for the emission band 647 nm under 449 nm excitation.

Sample	**τ** (μs)	η_{ETE} **(%)**	η_{QE} **(%)**
$NaLa_{0.97}Pr_{0.03}(MoO_4)_2$	6.52	-	100
$NaLa_{0.96}Pr_{0.03}Yb_{0.01}(MoO_4)_2$	6.40	1.80	102
$NaLa_{0.94}Pr_{0.03}Yb_{0.03}(MoO_4)_2$	6.38	2.14	103
$NaLa_{0.92}Pr_{0.03}Yb_{0.05}(MoO_4)_2$	6.33	2.91	104
$NaLa_{0.89}Pr_{0.03}Yb_{0.08}(MoO_4)_2$	6.17	5.36	106
$NaLa_{0.86}Pr_{0.03}Yb_{0.11}(MoO_4)_2$	6.01	7.82	108
$NaLa_{0.83}Pr_{0.03}Yb_{0.14}(MoO_4)_2$	5.96	8.58	109