Supplementary Information (SI) for Journal of Materials Chemistry C.

Oxygen-Induced Downshifting and Lanthanide Upconversion Luminescence in Sr_2YbF_7 Nanoparticles for Dual-Mode Security Applications

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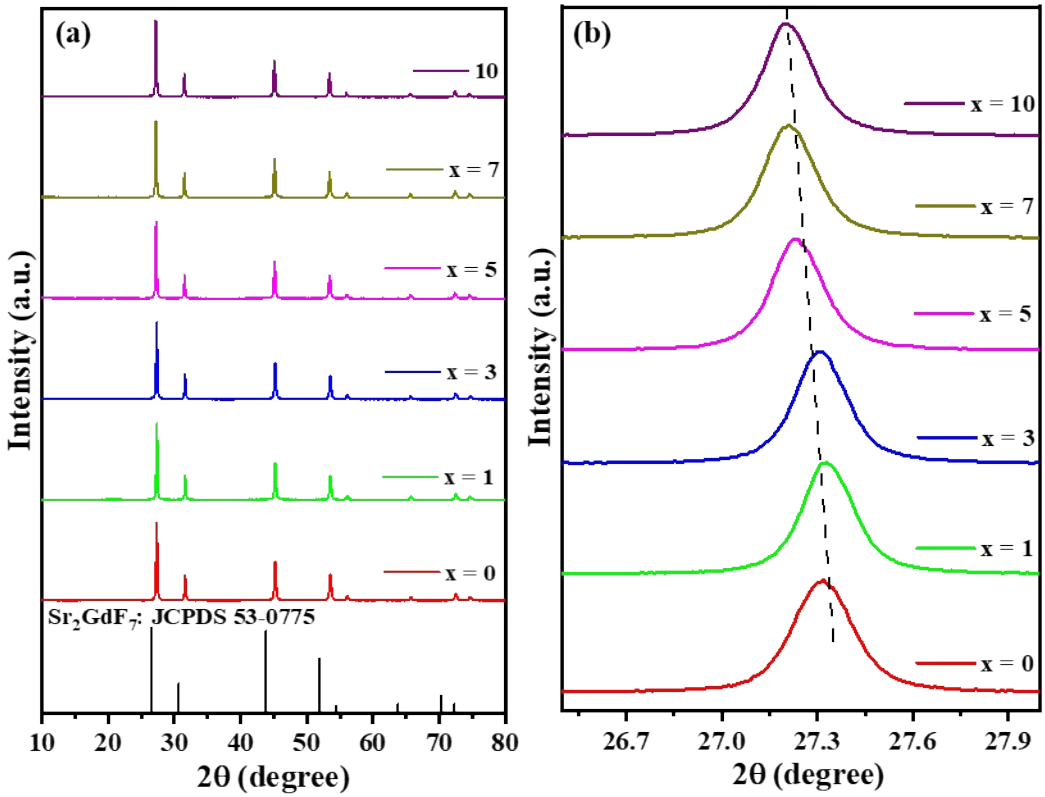


Figure S1:(a) *XRD patterns of Sr_2YbF_7: x% Ho^{3+} nanoparticles,* ***(b)*** *Zoomed XRD patterns within the 26.5–28° 2θ range.*

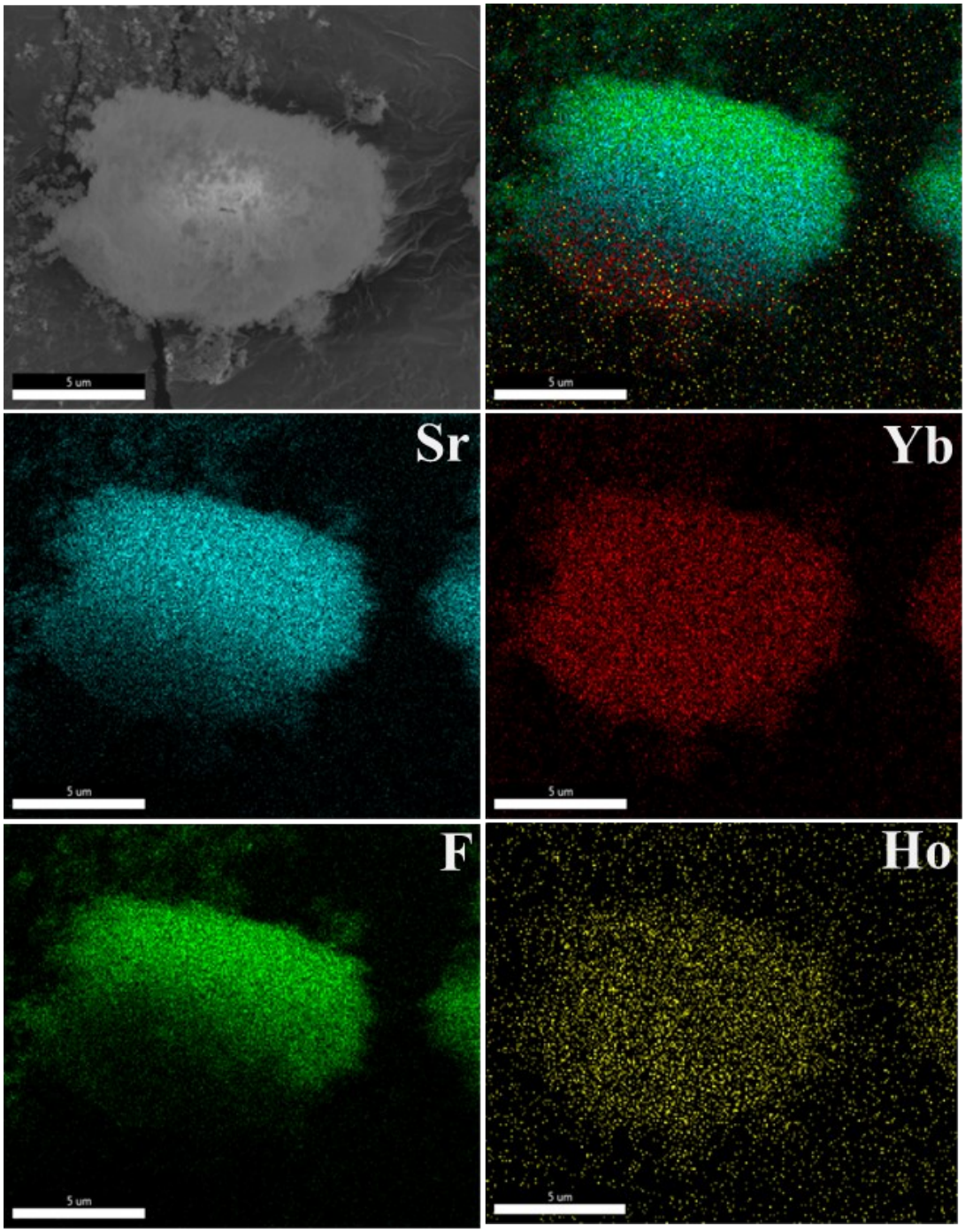


Figure S2: FESEM (field emission scanning electron microscopy) image and elemental mapping of the SYF: 7% Ho^{3+} by using FESEM-EDX (energy-dispersive X-ray analysis).

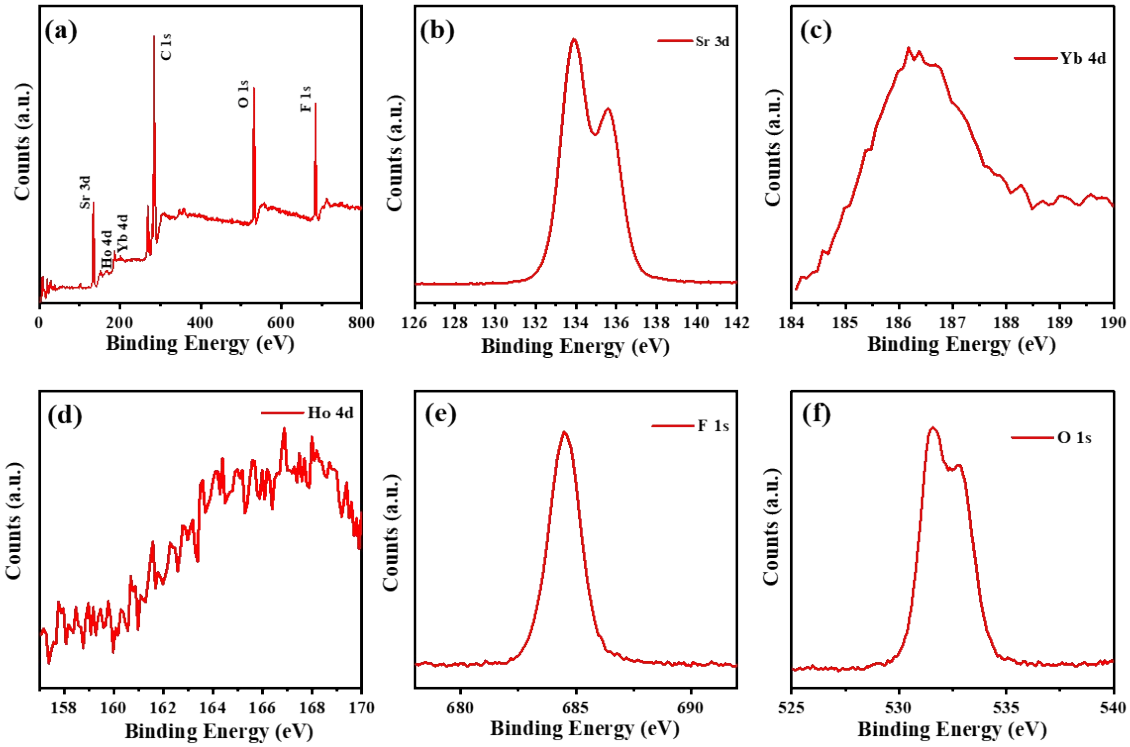


Figure S3: ***(a)*** Survey scan and High-resolution XPS spectra for ***(b)*** Sr 3d, ***(c)*** Yb 4d, ***(d)*** Ho 4d, ***(e)***, F 1s and ***(f)*** O 1s region of the Sr_2YbF_7: 7% Ho^{3+} sample.

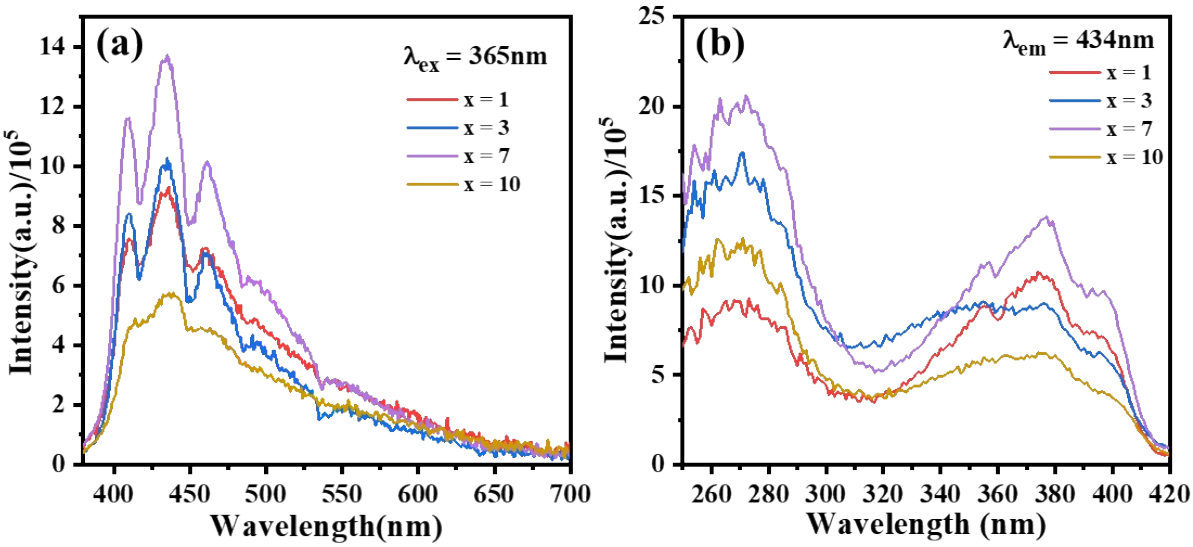
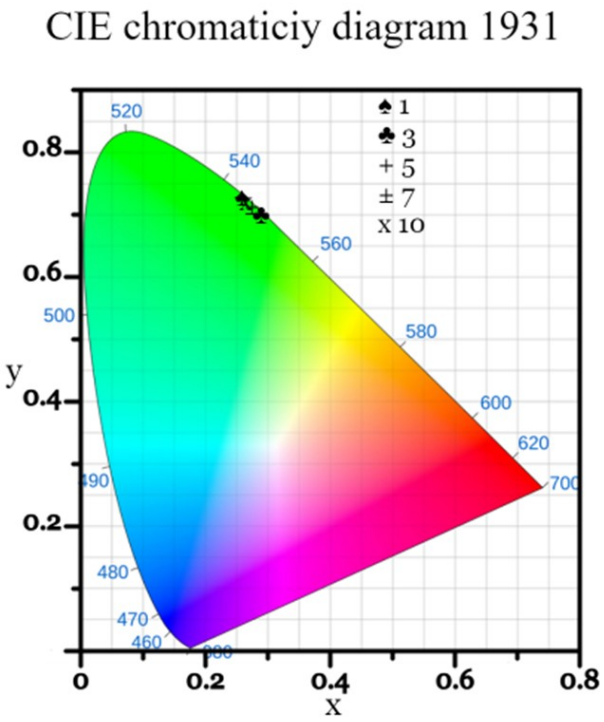


Figure S4: The room temperature solid-state excitation and emission spectra of the SYF: x% Ho^{3+} (each plot shows the wavelengths used for excitation and emission): ***(a)*** Emission spectra at 365 nm, ***(b)*** 434 nm excitation spectra.



S.No.	Con. of Ho^{3+} (%)	x	y
1.	1	0.26	0.73
2.	3	0.29	0.70
3.	5	0.26	0.73
4.	7	0.27	0.71
5.	10	0.27	0.72

Figure S5: CIE 1931 chromaticity diagram and colour coordinates (x, y) of SYF: x% Ho nanomaterials at 980 nm excitation.

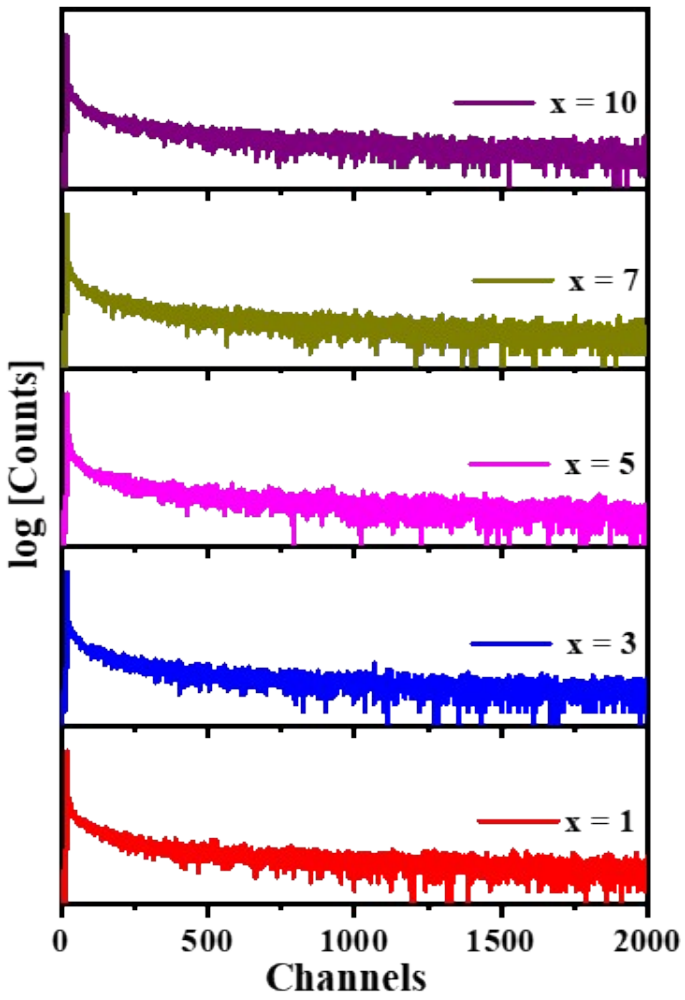


Figure S6: Decay curves of the Ho^{3+} excited state at 365 nm wavelength of the SYF: x% Ho^{3+}.

Table S1: PL decay curves of SYF as a function of Ho^{3+} concentration (λ_{ex} = 365 nm, λ_{em} = 434 nm).

Con. of Ho^{3+}	A_1	τ_1 (ns)	A_2	τ_2 (ns)	Avg. τ (ns)
1	23.75	16.4	76.25	171	166
3	25.43	16.4	74.57	161	155
5	25.64	16.9	74.36	156	150
7	25.17	16.3	74.83	151	145
10	25.25	11.6	74.75	146	142

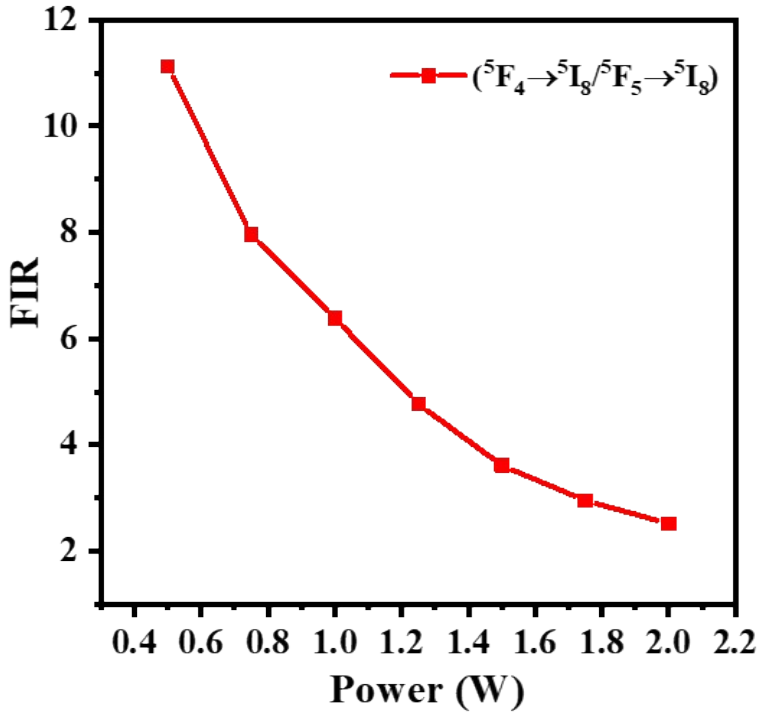


Figure S7: FIR of SYF: 7% Ho^{3+} nanomaterial as a function of pump power.

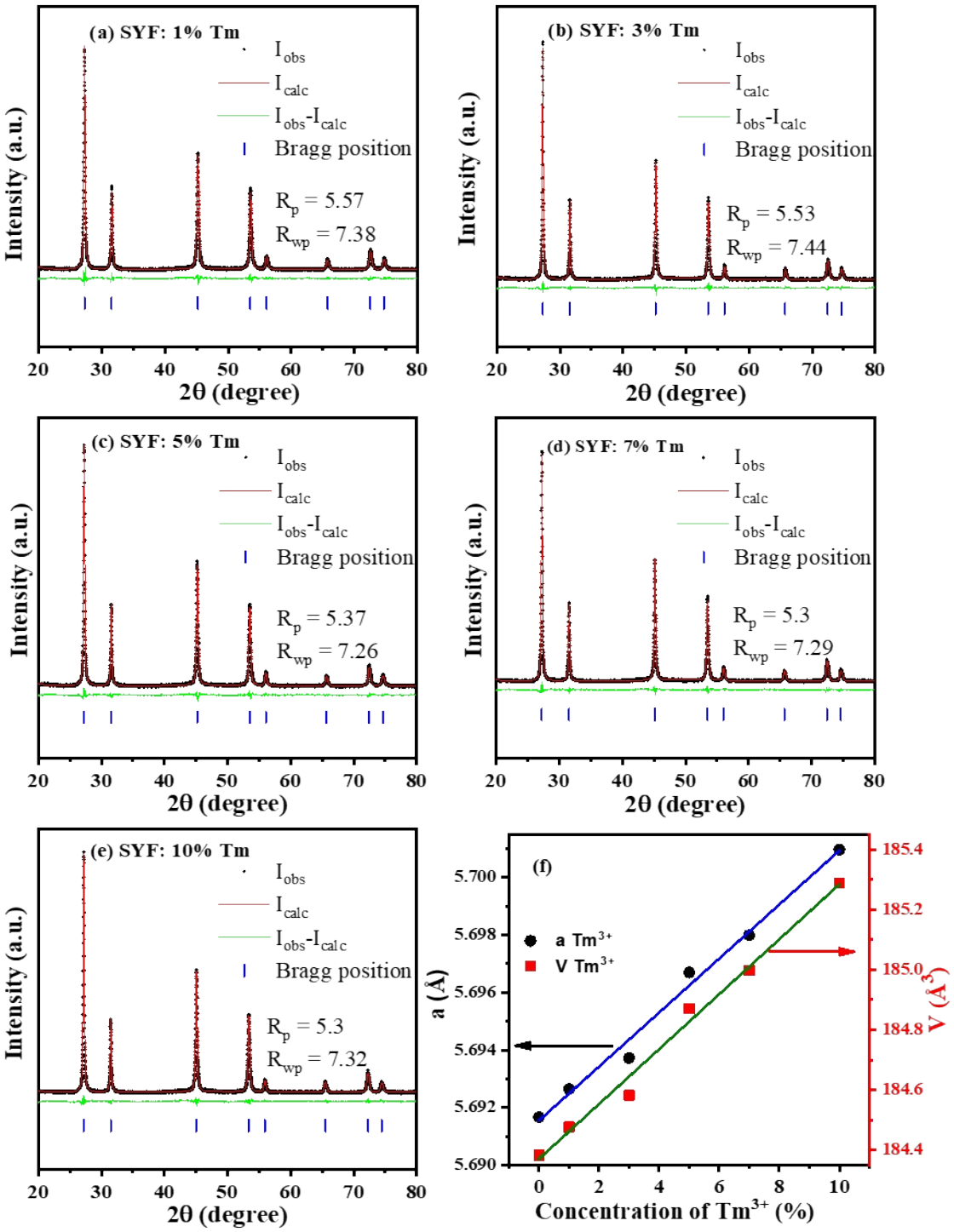


Figure S8: Rietveld refinement plot of the powder XRD data of sample $Sr_2Yb_{1-y}Tm_yF_7$.

Table S2: Refined structural parameters of the $Sr_2Yb_{1-y}Tm_yF_7$ samples.

Nominal composition	$Sr_2Yb_{0.99}Tm_{0.01}F_7$	$Sr_2Yb_{0.97}Tm_{0.03}F_7$	$Sr_2Yb_{0.95}Tm_{0.05}F_7$	$Sr_2Yb_{0.93}Tm_{0.07}F_7$	$Sr_2Yb_{0.90}Tm_{0.10}F_7$
x (%)	1	3	5	7	10
a (Å)	5.6926(1)	5.6937(1)	5.6967(1)	5.6980(1)	5.7010(1)
V $(Å)^3$	184.477(6)	184.582(5)	184.871(5)	184.998(5)	185.287(5)
FU	$Sr_{0.667}Yb_{0.330}Tm_{0.003}F_{2.333}$	$Sr_{0.667}Yb_{0.323}Tm_{0.010}F_{2.333}$	$Sr_{0.667}Yb_{0.317}Tm_{0.017}F_{2.333}$	$Sr_{0.667}Yb_{0.310}Tm_{0.023}F_{2.333}$	$Sr_{0.667}Yb_{0.300}Tm_{0.033}F_{2.333}$
Z	4	4	4	4	4
M: *4c* (0,0,0)					
Occ					
Sr	0.667	0.667	0.667	0.667	0.667
Yb	0.330	0.323	0.317	0.310	0.300
Ho/Tm	0.003	0.010	0.017	0.023	0.033
F1: *8f* (¼, ¼, ¼)					
occ.	0.676(4)	0.695(4)	0.692(4)	0.721(4)	0.756(4)
F2: *32f* (*x*,*x*,*x*) *x*	0.4029(10)	0.4049(10)	0.4042(11)	0.4042(10)	0.4040(11)
Occ.	0.0844(22)	0.0865(21)	0.0800(21)	0.0873(20)	0.0744(21)
U_{iso} $(Å)^2$	0.0262(4)	0.0254(4)	0.0274(4)	0.0224(4)	0.0241(4)
wR (%)	7.38	7.44	7.26	7.29	7.32
R (%)	5.57	5.53	5.37	5.3	5.3
GOF	2.18	2.16	2.16	2.06	2.08
FU estimated	$Sr_{0.667}Yb_{0.333}Tm_{0.003}F_{1.721}O_{0.306}$	$Sr_{0.667}Yb_{0.323}Tm_{0.010}F_{1.721}O_{0.306}$	$Sr_{0.667}Yb_{0.317}Tm_{0.017}F_{1.715}O_{0.309}$	$Sr_{0.667}Yb_{0.310}Tm_{0.023}F_{1.948}O_{0.193}$	$Sr_{0.667}Yb_{0.300}Tm_{0.033}F_{1.881}O_{0.226}$

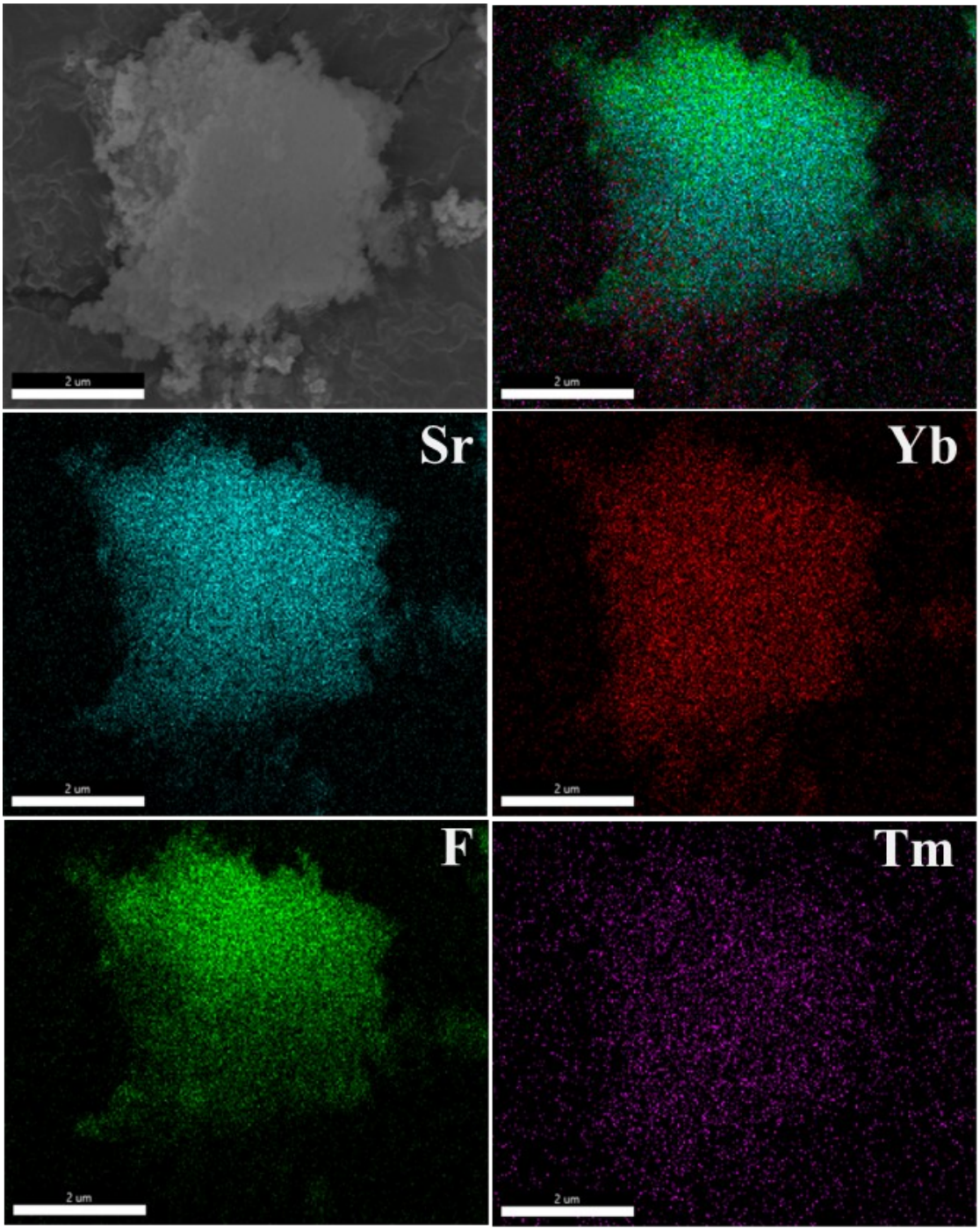


Figure S9: FESEM image and elemental mapping of the SYF: 5% Tm^{3+} by using FESEM-EDX.

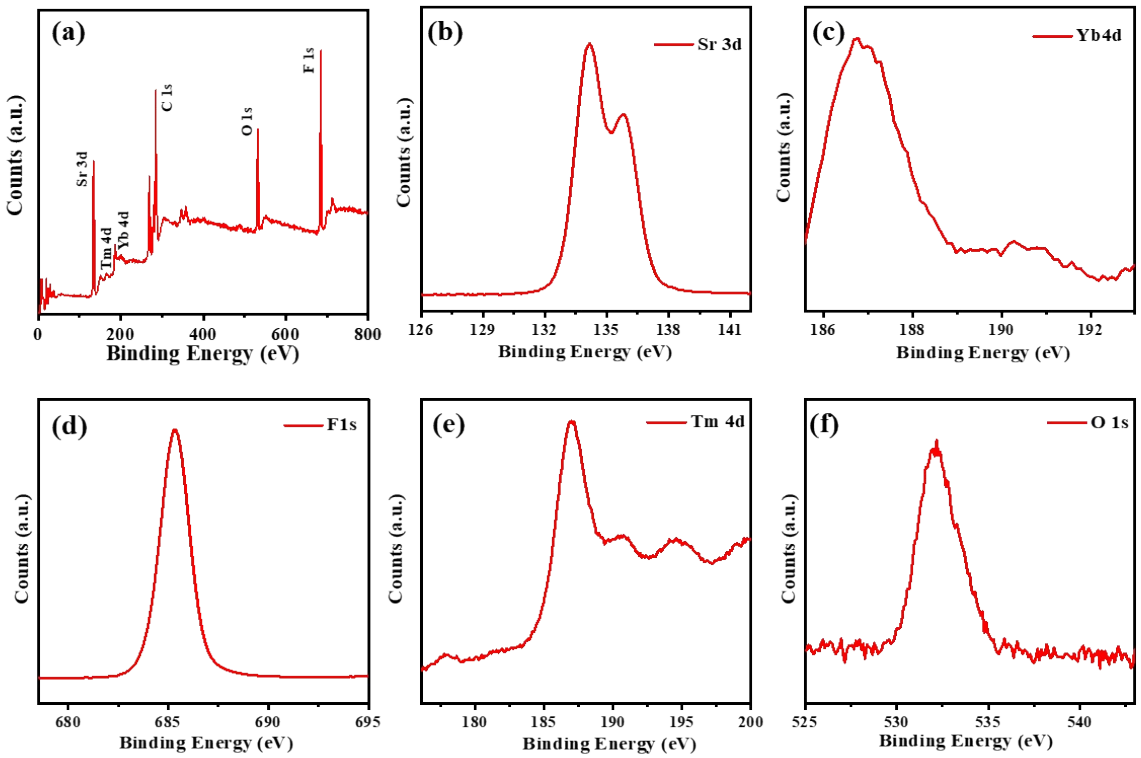


Figure S10: (a) Survey scan and High-resolution XPS spectra for (b) Sr 3d, (c) Yb 4d, (d) F 1s, (e) Tm 4d and (f) O 1s region of the Sr_2YbF_7: 5% Tm^{3+} sample.

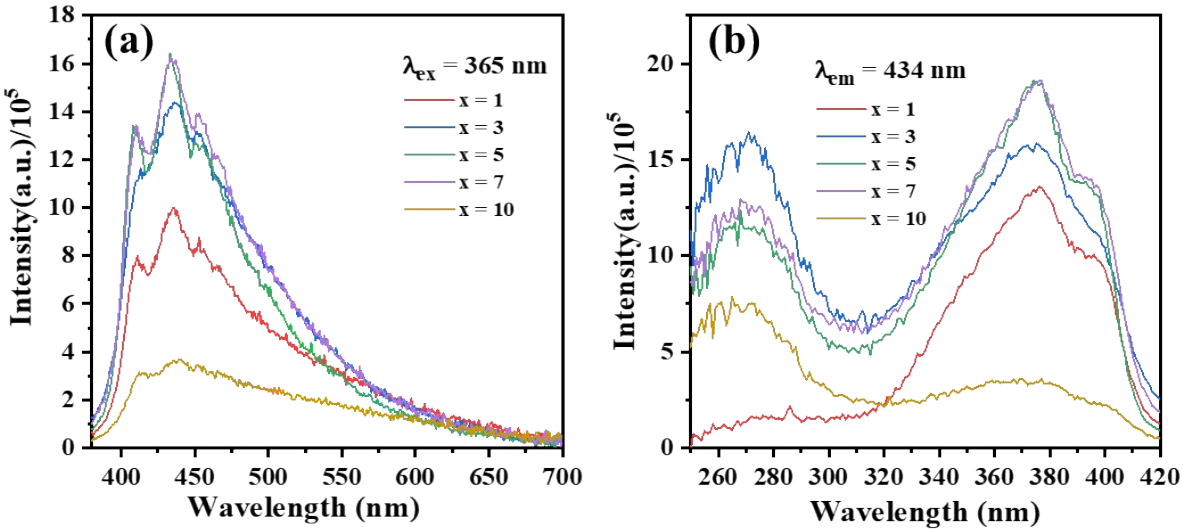
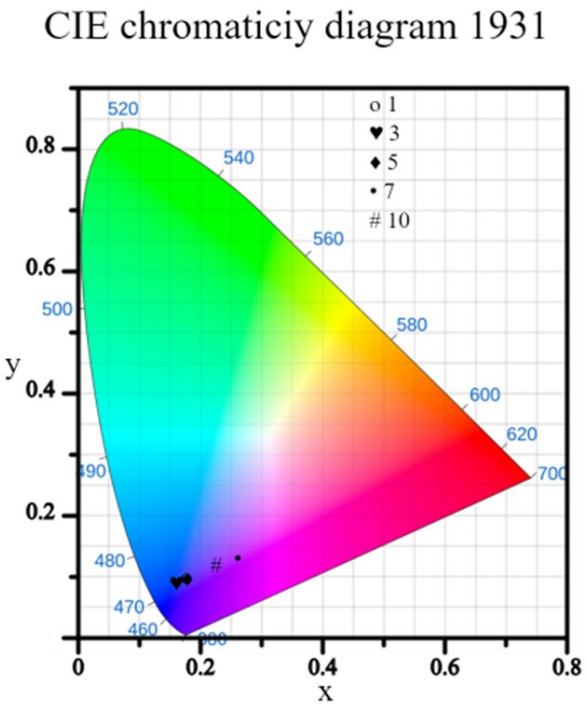


Figure S11: Emission and excitation spectra of the SYF doped with Tm^{3+}. With excitation wavelengths of ***(a)*** 365 nm the emission spectra was captured, ***(b)*** At 434 nm, the excitation spectra was tracked.



S.No.	Con. of Tm^{3+} (%)	x	y
1.	1	0.178	0.1
2.	3	0.16	0.088
3.	5	0.175	0.095
4.	7	0.265	0.129
5.	10	0.227	0.118

Figure S12: CIE 1931 chromaticity diagram and colour coordinates (x, y) of SYF: y% Tm nanomaterials at 980 nm excitation.

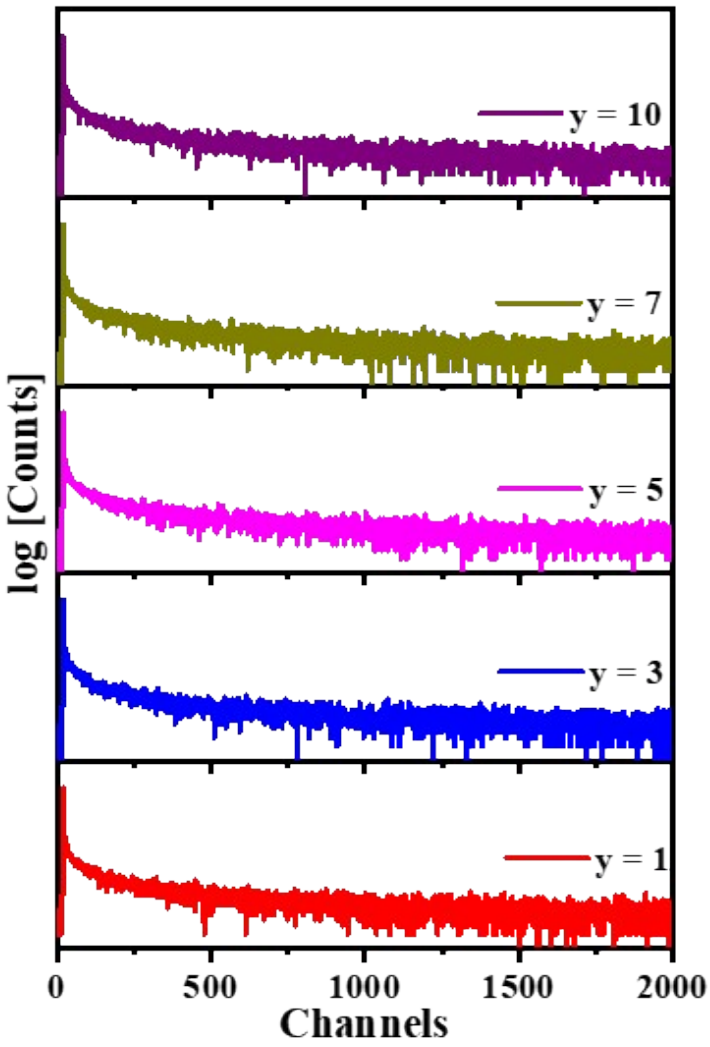


Figure S13: Decay curves of the Tm^{3+} excited state at 365 nm wavelength of the SYF: y% Tm^{3+}.

Table S3: PL decay curves of SYF as a function of Tm^{3+} concentration (λ_{ex} = 365 nm, λ_{em} = 434 nm).

Con. of Tm^{3+}	A_1	τ_1 (ns)	A_2	τ_2	Avg. τ (ns)
1	21.87	18.0	78.13	172	167
3	24.52	18.2	75.48	169	164
5	25.37	15.0	74.63	166	162
7	24.91	15.3	75.09	166	161
10	25.33	16.6	74.67	165	160

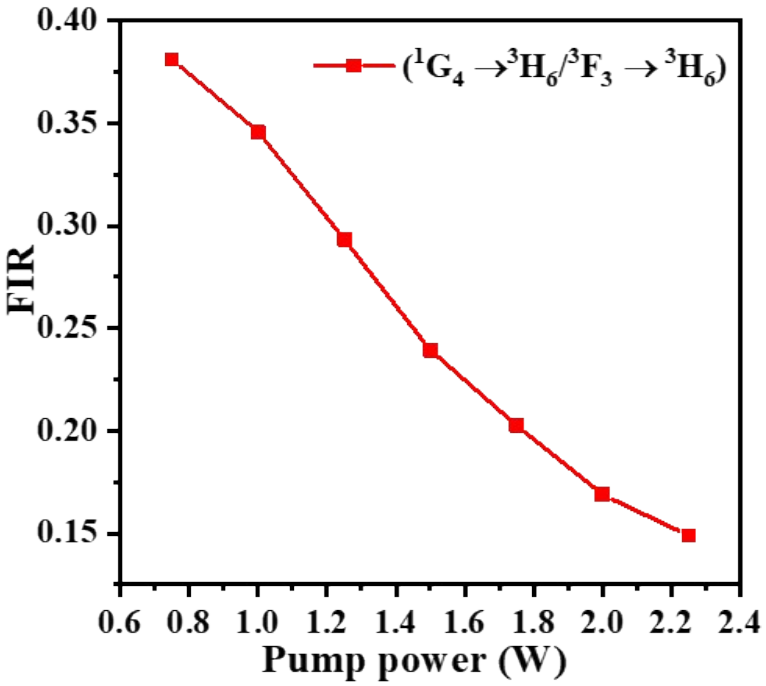


Figure S14: FIR of SYF: 5% Tm^{3+} nanomaterial as a function of pump power.

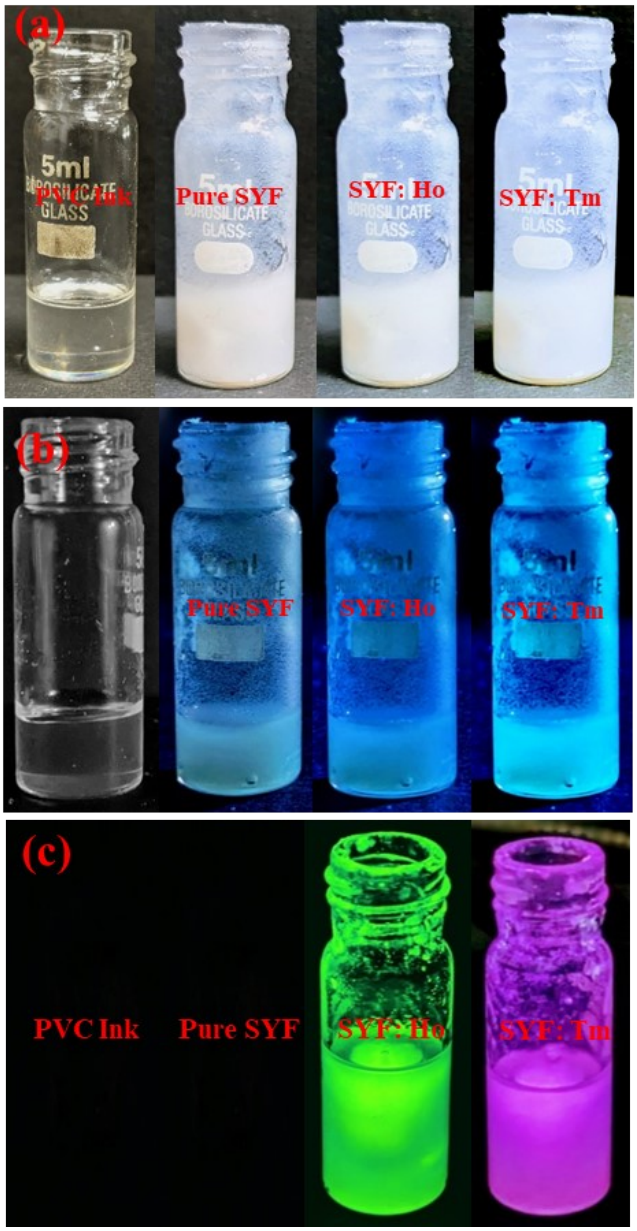


Figure S15: Photograph of PVC ink, ink prepared with undoped sample, SYF: 7% Ho^{3+} and SYF: 5 % Tm^{3+} (a) under daylight, (b) under 365 nm UV light, (b) under 980 nm NIR light.

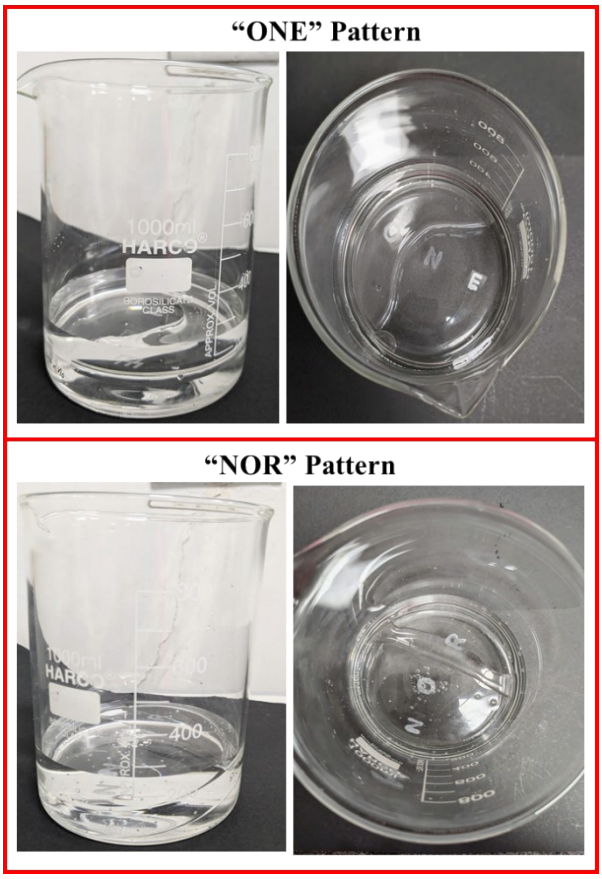


Figure S16: Five hours of stability testing of printed patterns in water