Electronic Supplementary Material (ESI) for RSC Advances.

Supporting information for

Intense UV upconversion through highly sensitized $NaRF_4$,Tm (R:Y,Yb) crystals

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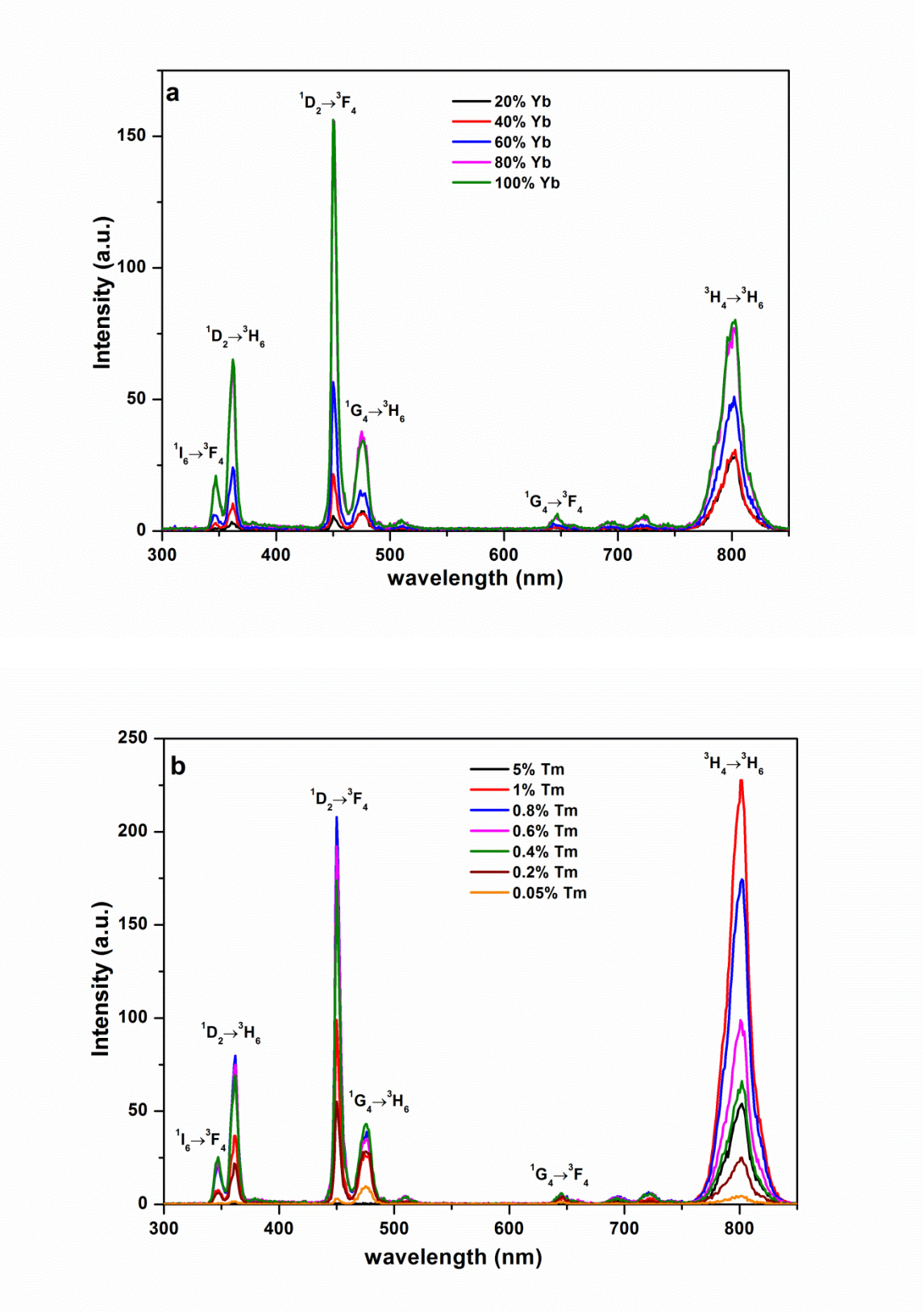
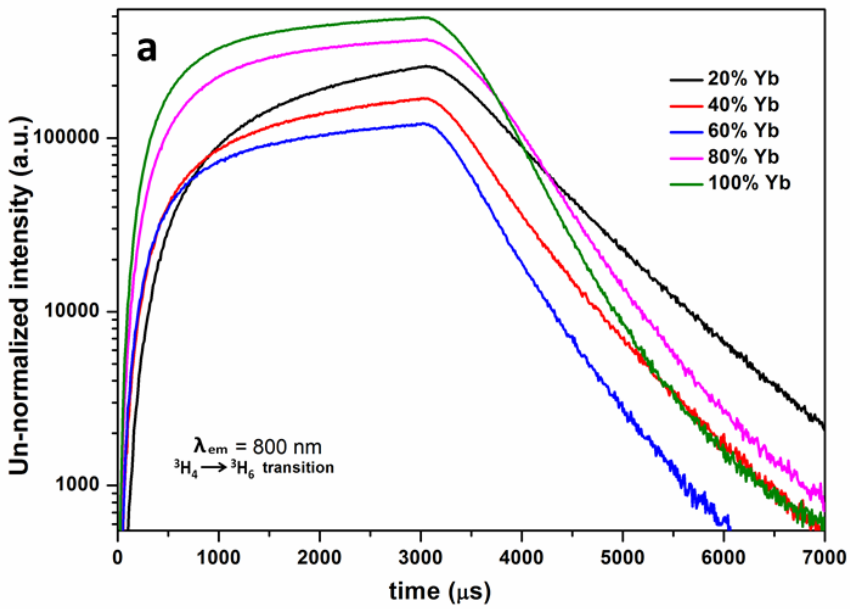
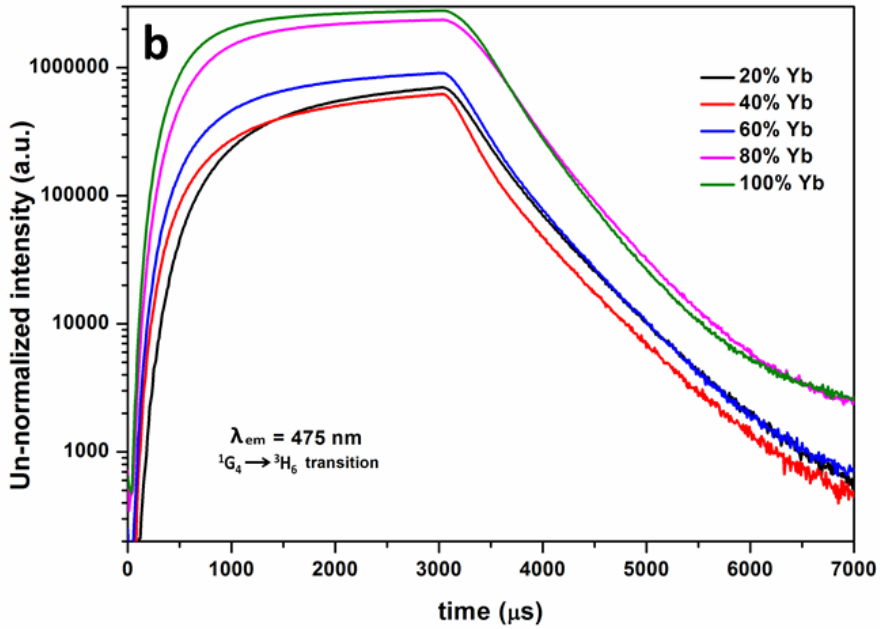


Fig. S1 Upconversion luminescence spectra of a) $NaY_{1-x}Yb_xF_4$:Tm (0.5%) and b) $NaYbF_4$:Tm (x%) nanocrystal dispersion in oleic acid pumped by a 980 nm laser.


a
20% Yb
40% Yb
60% Yb
80% Yb
100% Yb
Un-normalized intensity (a.u.)
100000
10000
1000
λem = 800 nm
3H4 → 3H6 transition
0
1000
2000
3000
4000
5000
6000
7000
time (μs)


b
20% Yb
40% Yb
60% Yb
80% Yb
100% Yb
Un-normalized intensity (a.u.)
1000000
100000
10000
1000
λem = 475 nm
1G4 → 3H6 transition
0
1000
2000
3000
4000
5000
6000
7000
time (μs)

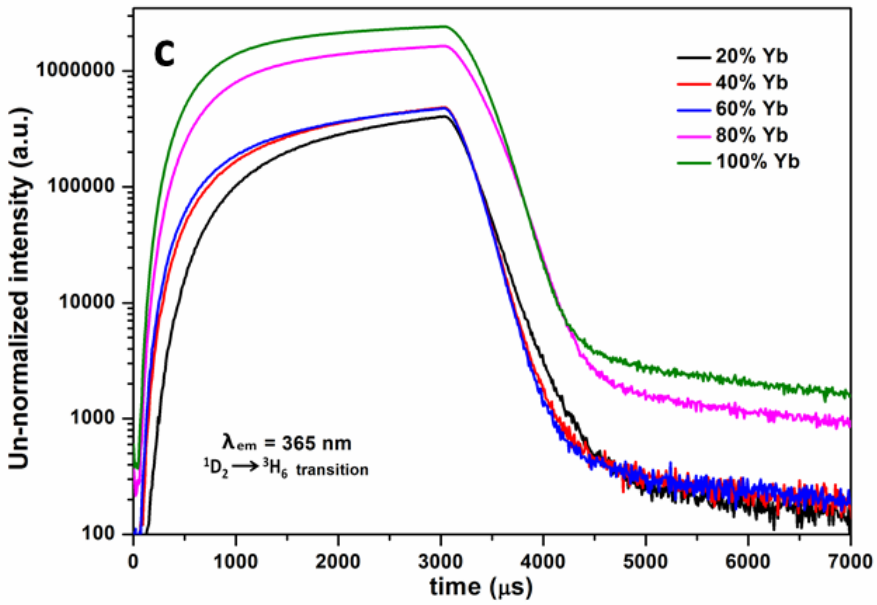
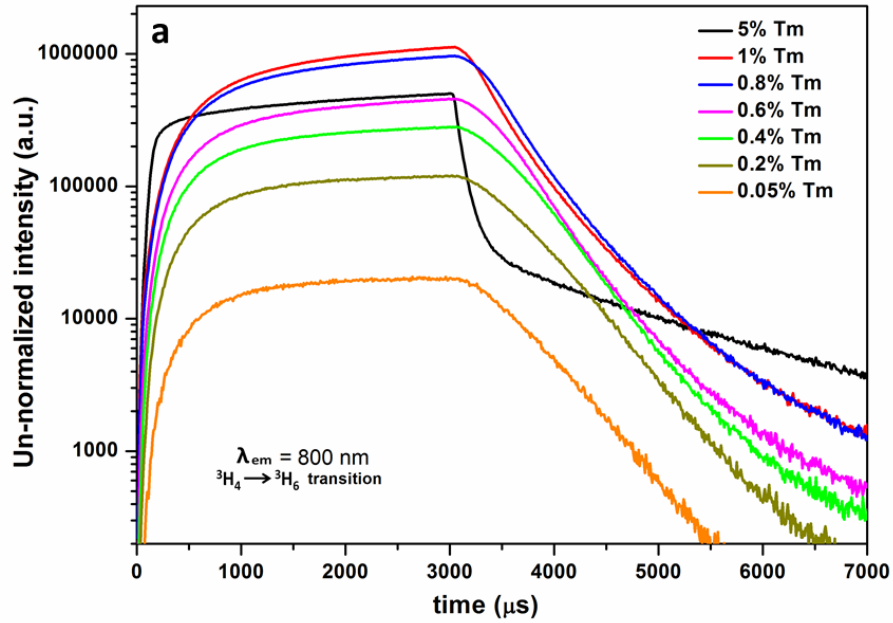


Fig. S2 Non-normalized spectra of upconversion luminescence decay of the $NaY_{1-x}Yb_xF_4$:Tm (0.5%) nanocrystal dispersion in oleic acid for the a) 800 nm, b) 475 nm and c) 365 nm emissions upon 980 nm excitation for 0-3000 μs.



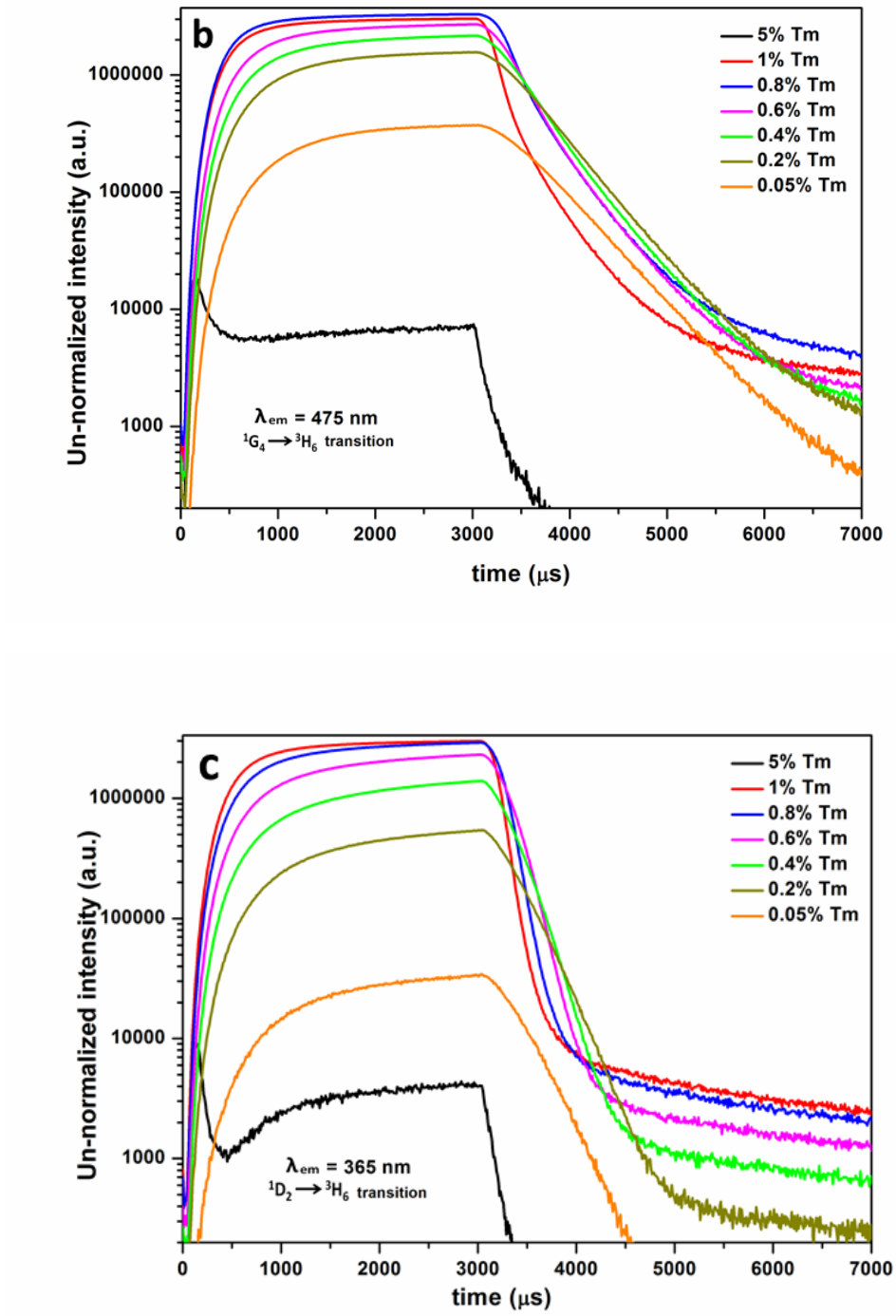


Fig. S3 Non-normalized spectra of upconversion luminescence decay of the $NaYbF_4$:Tm (x%) nanocrystal dispersion in oleic acid for the a) 800 nm, b) 475 nm and c) 365 nm emissions upon 980 nm excitation for 0-3000 μs.

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Table S1. Summary of decay times of $^3H_4$, $^1G_4$ and $^1D_2$ level of $NaY_{1-x}Yb_xF_4$:Tm (0.5%) and $NaYbF_4$:Tm (x%) with respective relative amplitude.

Yb^{3+} (mol %) #	$^3H_4 \rightarrow {}^3H_6$ (800 nm)		$^1G_4 \rightarrow {}^3H_6$ (475 nm)		$^1D_2 \rightarrow {}^3H_6$ (365 nm)	
	τ(µs)	amplitude (%)	τ(µs)	amplitude (%)	τ(µs)	amplitude (%)
20	630 ± 8	81	576 ± 2	56	168 ± 0.3	100
40	422 ± 5	80	547 ± 2	50	142 ± 0.3	100
60	378 ± 7	78	224 ± 2	56	138 ± 0.3	100
80	440 ± 5	88	362 ± 2	92	157 ± 0.4	100
100	375 ± 1	97	293 ± 4	77	137 ± 0.3	100
Tm^{3+} (mol %)#	$^3H_4 \rightarrow {}^3H_6$ (800 nm)		$^1G_4 \rightarrow {}^3H_6$ (475 nm)		$^1D_2 \rightarrow {}^3H_6$ (365 nm)	
	τ(µs)	amplitude (%)	τ(µs)	amplitude (%)	τ(µs)	amplitude (%)
0.05	481 ± 4	100	510 ± 5	100	272 ± 1	100
0.2	470 ± 5	100	427 ± 0.5	100	235 ± 2	100
0.4	430 ± 7	100	358 ± 1	98	169 ± 0.5	100
0.6	321 ± 5	99	256 ± 3	98	125 ± 76	99
0.8	337 ± 2	94	169 ± 2	85	98 ± 0.2	99
1	275 ± 2	87	88 ± 0.5	93	82 ± 0.3	99
5	70 ± 0.5	91	82 ± 3	85	80 ± 10	72

Note: Only the major lifetime component (with the highest amplitude) in case of multiexponential decay. Samples with 100% amplitude had a single decay time. # the percentages are with respect to the added quantity in the synthesis.

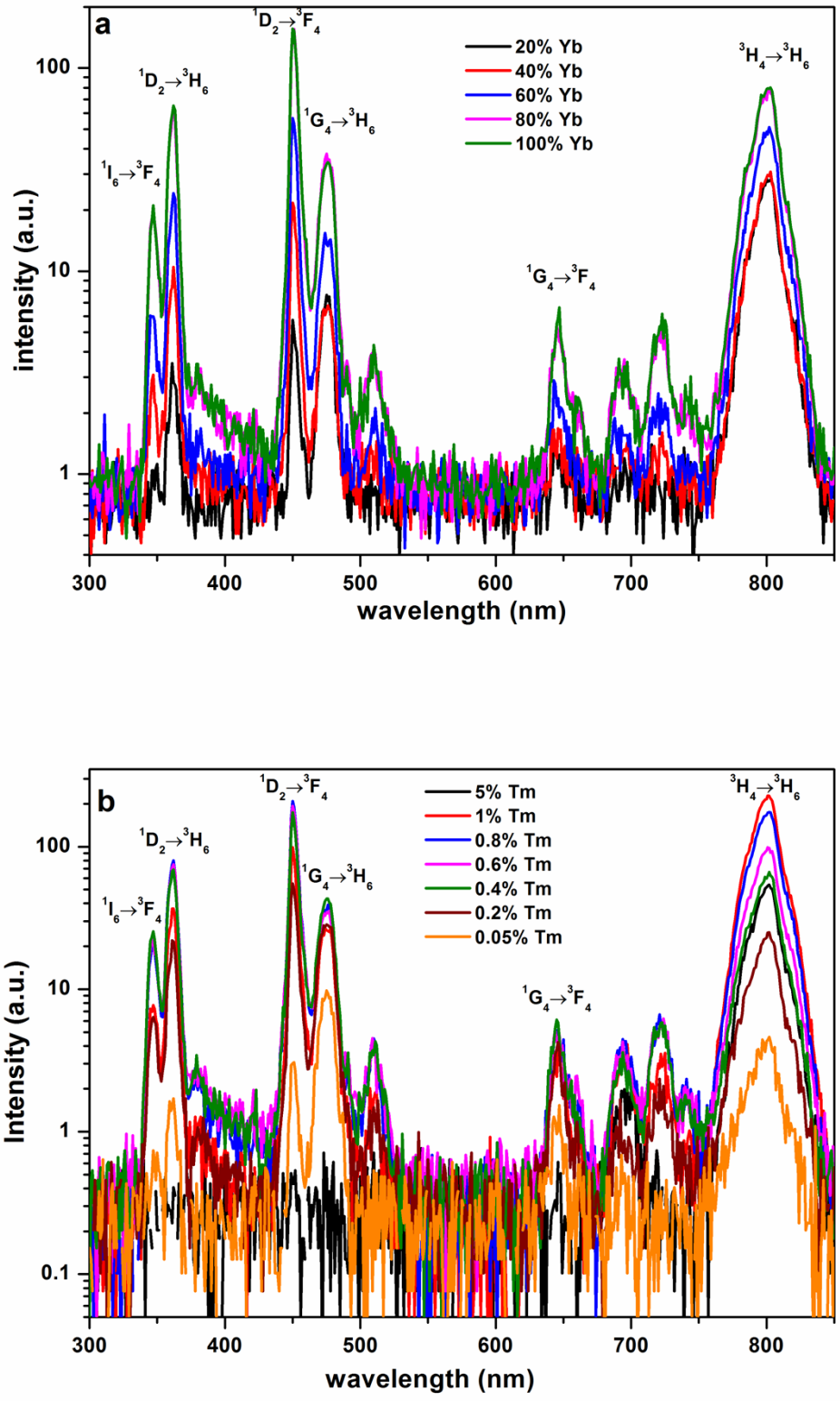

Fig. S4 Upconversion luminescence spectra of a) $NaY_{1-x}Yb_xF_4$:Tm (0.5%) and b) $NaYbF_4$:Tm (x%) nanocrystal dispersion in oleic acid pumped by a 980 nm laser.

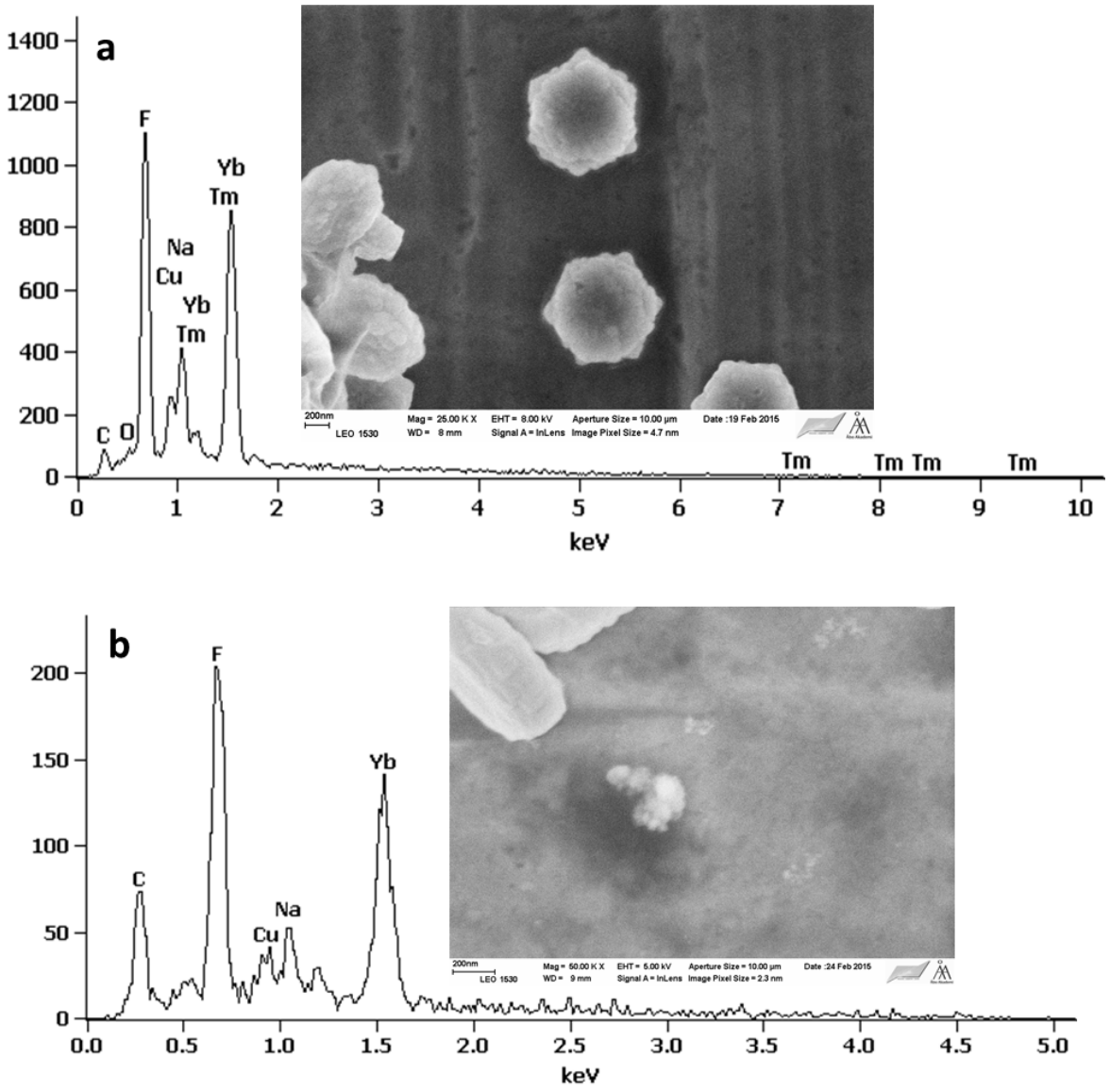

Fig. S5 EDX analysis of a) large and b) small $NaYbF_4$:Tm (0.8%) nanoparticles with corresponding SEM images.

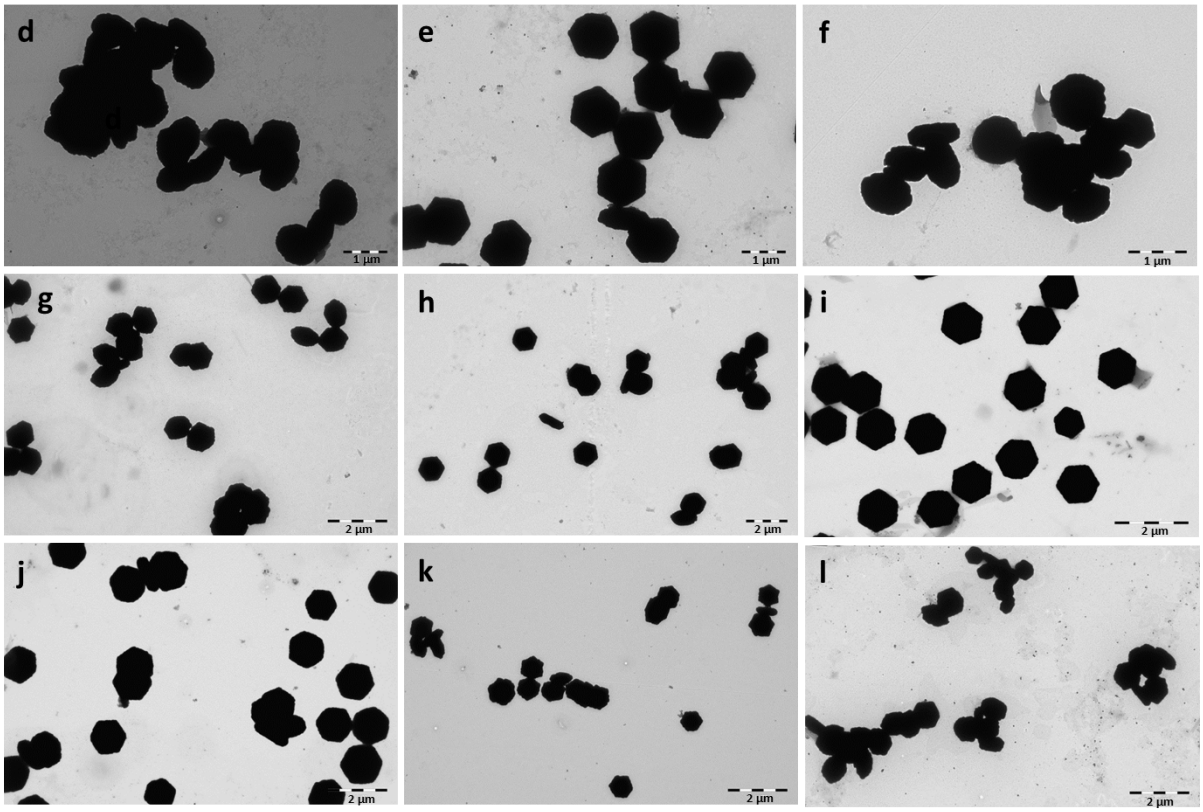

Fig. S6 TEM images of hexagonal $NaY_{1-x}Yb_xF_4$:Tm (0.5%) with different concentrations of Yb^{3+}: d) 80 and e) 100% and $NaYbF_4$:Tm (x%) crystals with different concentrations of Tm^{3+}: f) 0.05, g) 0.2, h) 0.4, i) 0.6, j) 0.8, k) 1 and l) 5%.