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Supplementary material

Multi-color emission in monodispersed spheres of tetragonal yttrium phosphate: microwave-assisted fast synthesis, formation mechanism, temperature-dependent luminescence, and application in anti-fake label

Qi Zhu[1,2*], Zhixin Xu[1,2], Zhihao Wang[1,2,3], Xuejiao Wang[4], Xiaodong Li[1,2], Xudong Sun[1,2] and Ji-Guang Li[3*]

[1]*Key Laboratory for Anisotropy and Texture of Materials (Ministry of Education), Northeastern University, Shenyang, Liaoning 110819, China*

[2]*Institute of Ceramics and Powder Metallurgy, School of Materials Science and Engineering, Northeastern University, Shenyang, Liaoning 110819, China*

[3]*Research Center for Functional Materials, National Institute for Materials Science, Namiki 1-1, Tsukuba, Ibaraki 305-0044, Japan*

[4]*College of New Energy, Bohai University, Jinzhou, Liaoning 121013 China*

*E-mail: zhuq@smm.neu.edu.cn and LI.Jiguang@nims.go.jp

Table S1. Lattice parameters and crystal sizes of YPO_4 and $(Y,Ln)PO_4$ (Ln=Eu, Tb, Dy, Ho, Tm, Ce, and Tb/Eu) obtained from XRD data in Fig. 1.*

Sample	*a*=*b* (nm)	*c* (nm)	Crystal sizes (nm)	Particle sizes (μm)
YPO_4	0.6893	0.6046	17	0.98±0.2
$(Y_{0.95}Eu_{0.05})PO_4$	0.6906	0.6072	18	0.96±0.1
$(Y_{0.95}Tb_{0.02})PO_4$	0.6896	0.6057	17	1.53±0.2
$(Y_{0.99}Dy_{0.01})PO_4$	0.6896	0.6055	17	1.13±0.1
$(Y_{0.99}Ho_{0.01})PO_4$	0.6892	0.6053	17	0.74±0.2
$(Y_{0.99}Tm_{0.01})PO_4$	0.6886	0.6043	16	1.00±0.1
$(Y_{0.99}Ce_{0.01})PO_4$	0.6904	0.6078	20	0.83±0.1
$(Y_{0.88}Tb_{0.02}Eu_{0.10})PO_4$	0.6906	0.6074	20	0.88±0.2

**a*=*b*=~0.68780 nm and *c*=~0.60360 nm in YPO_4 (JCPDS No. 74-2429). Lattice parameters and crystal sizes are the average values. Average diameter and standard size deviation of the spheres were determined from at least 100 individual particles in the FE-SEM micrograph, using the "SMile View" image processing software (Ver. 2.1, JEOL).

Table S2. Results of chemical analysis of the as-prepared $(Y,Ln)PO_4$ (Ln=Eu, Tb, Dy, Ho, Tm, Ce, and Tb/Eu) and the derived chemical formula.

Sample ID	Chemical analysis (wt%)				Chemical Formula
	Y	Eu	P		
S1	37.2	3.23	14.7		$(Y_{0.952}Eu_{0.048})PO_4 \cdot 1.83H_2O$
	Y	Tb	P		
S2	38.8	1.43	15.8		$(Y_{0.980}Tb_{0.020})PO_4 \cdot 1.40H_2O$
	Y	Dy	P		
S3	38.9	0.72	14.9		$(Y_{0.990}Dy_{0.010})PO_4 \cdot 1.79H_2O$
	Y	Ho	P		
S4	39.1	0.75	15.1		$(Y_{0.990}Ho_{0.010})PO_4 \cdot 1.71H_2O$
	Y	Tm	P		
S5	38.7	0.74	15.1		$(Y_{0.990}Tm_{0.010})PO_4 \cdot 1.80H_2O$
	Y	Ce	P		
S6	39.0	0.59	15.2		$(Y_{0.990}Ce_{0.010})PO_4 \cdot 1.71H_2O$
	Y	Tb	Eu	P	
S7	33.5	1.35	6.28	15.1	$(Y_{0.883}Tb_{0.020}Eu_{0.097})PO_4 \cdot 1.65H_2O$

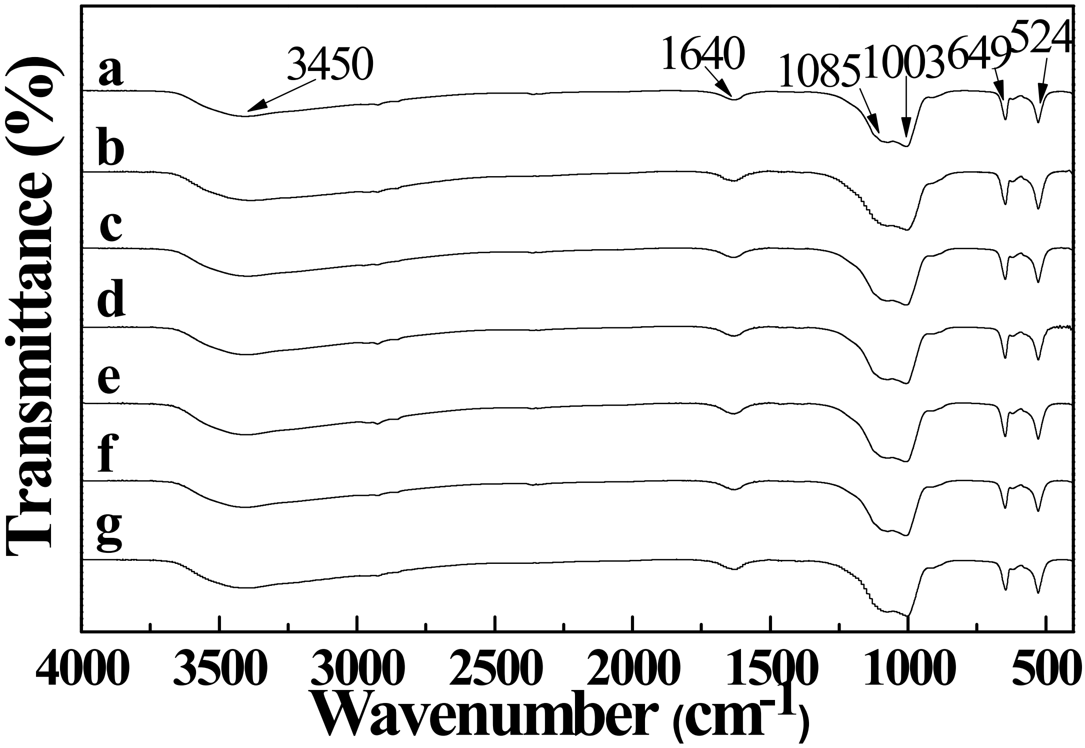


Fig. S1 FT-IR spectra of (a) $(Y_{0.95}Eu_{0.05})PO_4$, (b) $(Y_{0.95}Tb_{0.02})PO_4$ (c) $(Y_{0.99}Dy_{0.01})PO_4$, (d) $(Y_{0.99}Ho_{0.01})PO_4$, (e) $(Y_{0.99}Tm_{0.01})PO_4$, (f) $(Y_{0.99}Ce_{0.01})PO_4$, and (g) $(Y_{0.88}Tb_{0.02}Eu_{0.10})PO_4$.

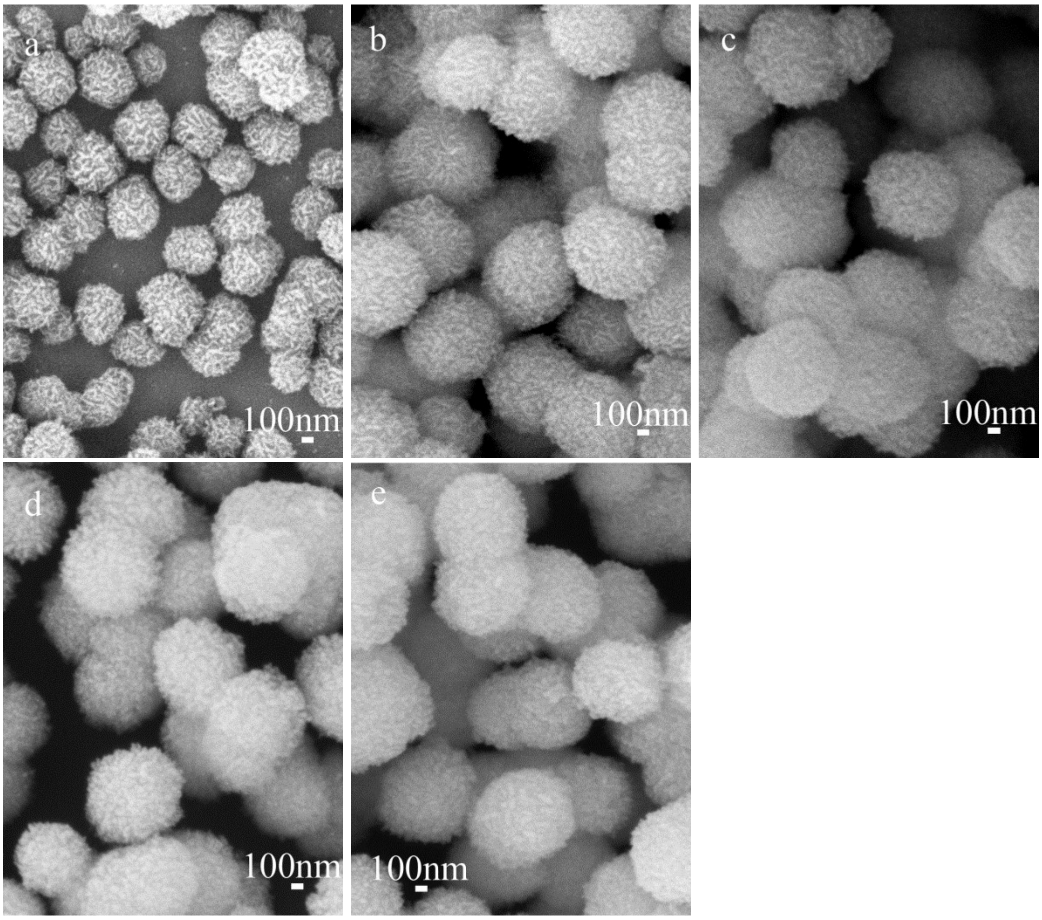


Fig. S2 FE-SEM micrographs showing morphologies of the $(Y_{0.98}Tb_{0.02})PO_4$ particles during growth: (a) 1min, (b) 3min, (c) 5min, (d) 10min, (e) 20min.

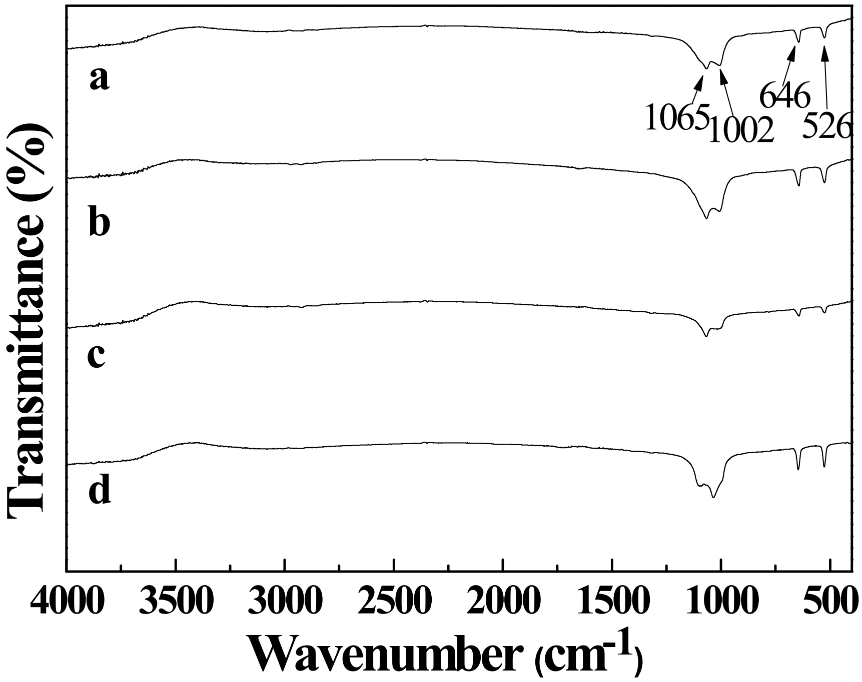


Fig. S3 FT-IR spectra of $(Y_{0.95}Eu_{0.05})PO_4$ powders calcined at (a) 600 °C, (b) 800 °C, (c) 1000 °C, (d) 1200 °C.

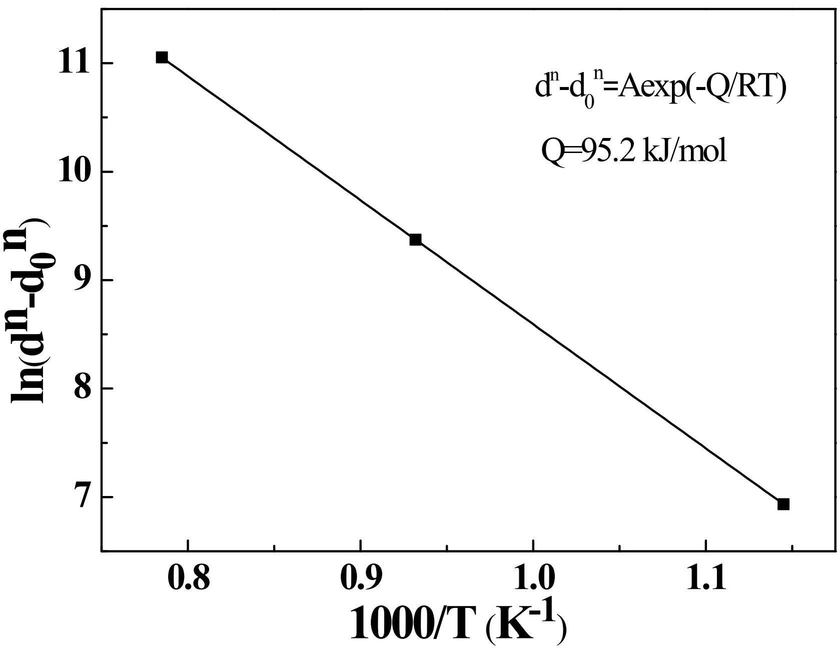


Fig. S4 Plot of $\ln(d^n-d_0^n)$ versus 1/T for crystallite growth of $(Y_{0.95}Eu_{0.05})PO_4$. In the equation $d^n-d_0^n=A\exp(-Q/RT)$, d and d_0 are the grain size and the size value of the 600°C product, respectively, A is a constant, R is the gas constant, T is the temperature in Kelvin, and Q is the activation energy for growth. The results are better fitted with n=3 in this work.

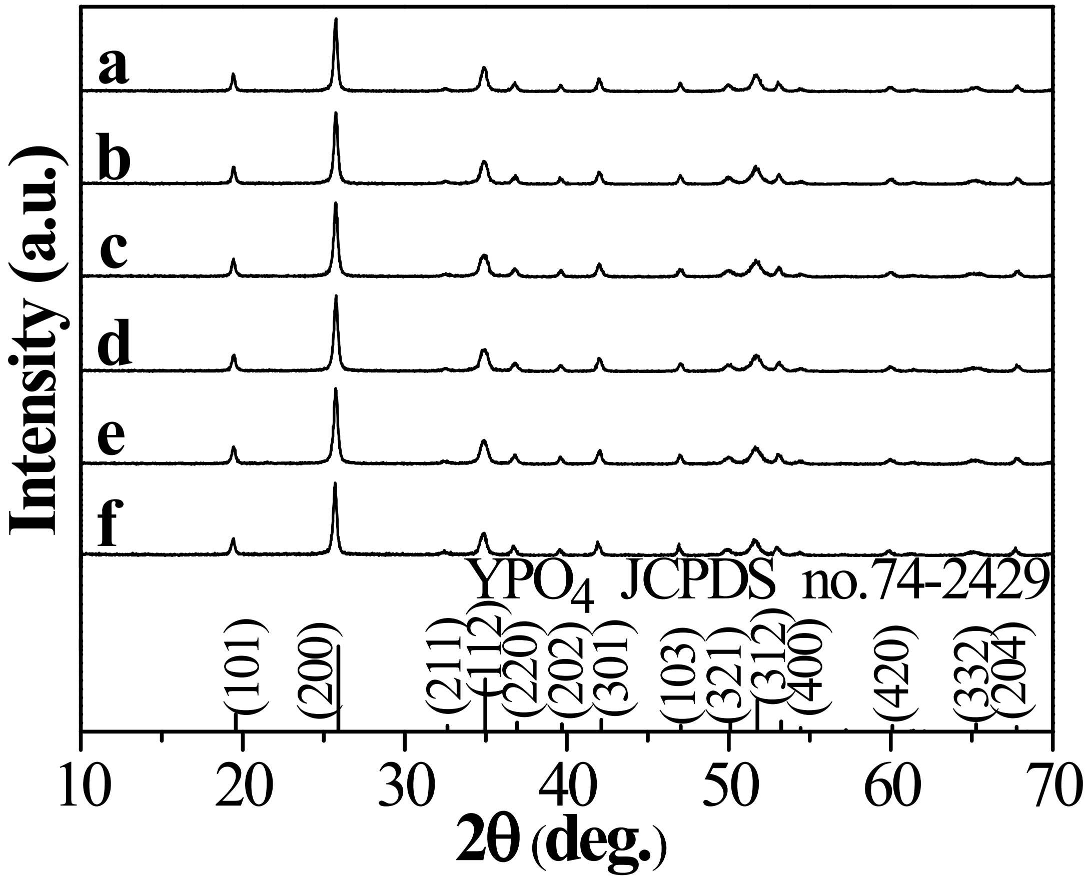


Fig. S5 XRD patterns of the particles calcined at 1000 ^{o}C, with (a) $(Y_{0.95}Tb_{0.02})PO_4$ (b) $(Y_{0.99}Dy_{0.01})PO_4$, (c) $(Y_{0.99}Ho_{0.01})PO_4$, (d) $(Y_{0.99}Tm_{0.01})PO_4$, (e) $(Y_{0.99}Ce_{0.01})PO_4$, and (f) $(Y_{0.88}Tb_{0.02}Eu_{0.10})PO_4$.

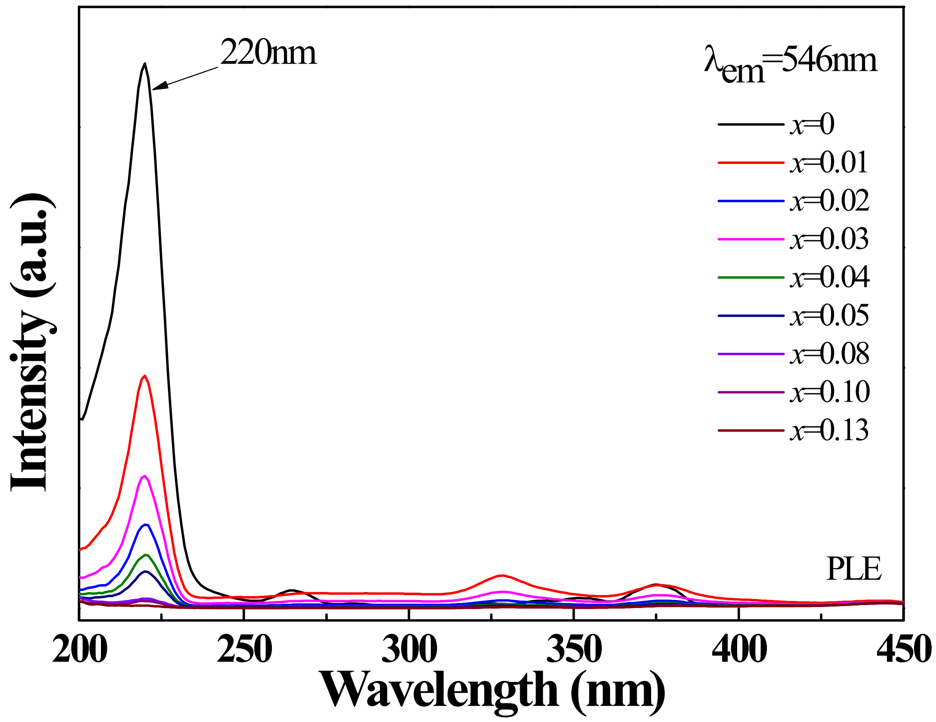
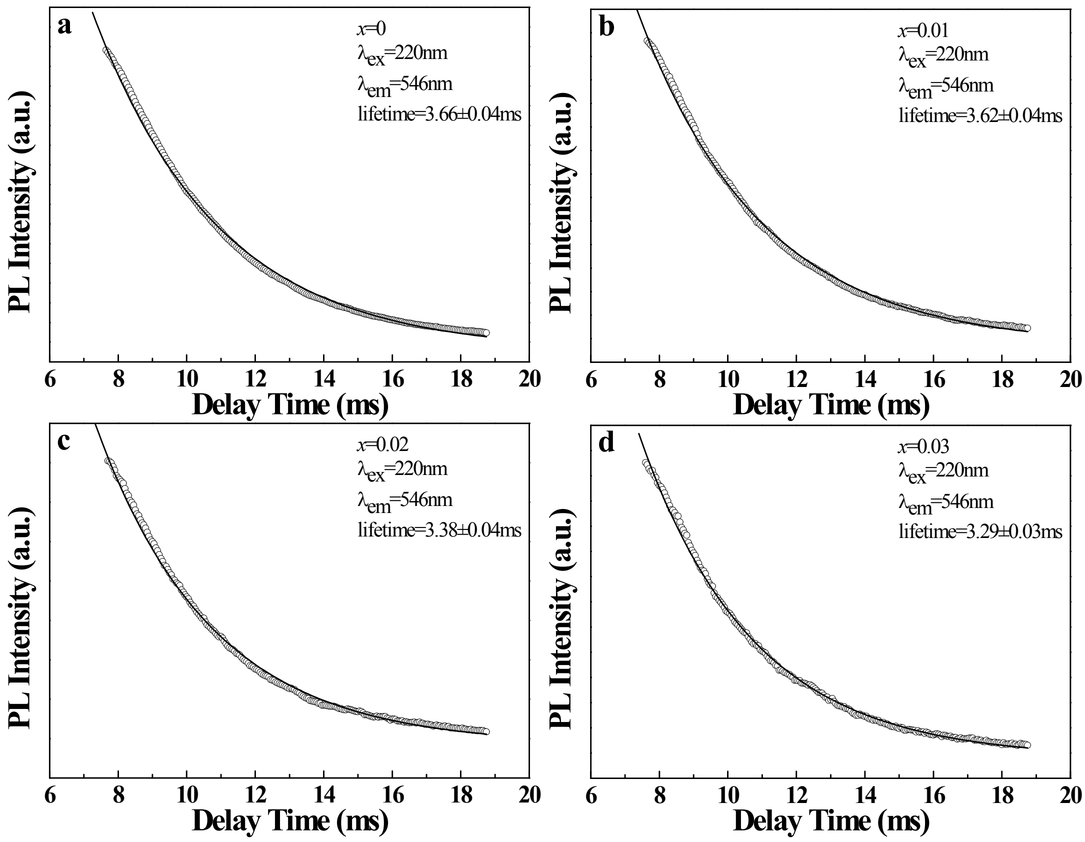


Fig. S6 Photoluminescence excitation (PLE) spectra of $(Y_{0.98-x}Tb_{0.02}Eu_x)PO_4$ calcined at 1000 °C.



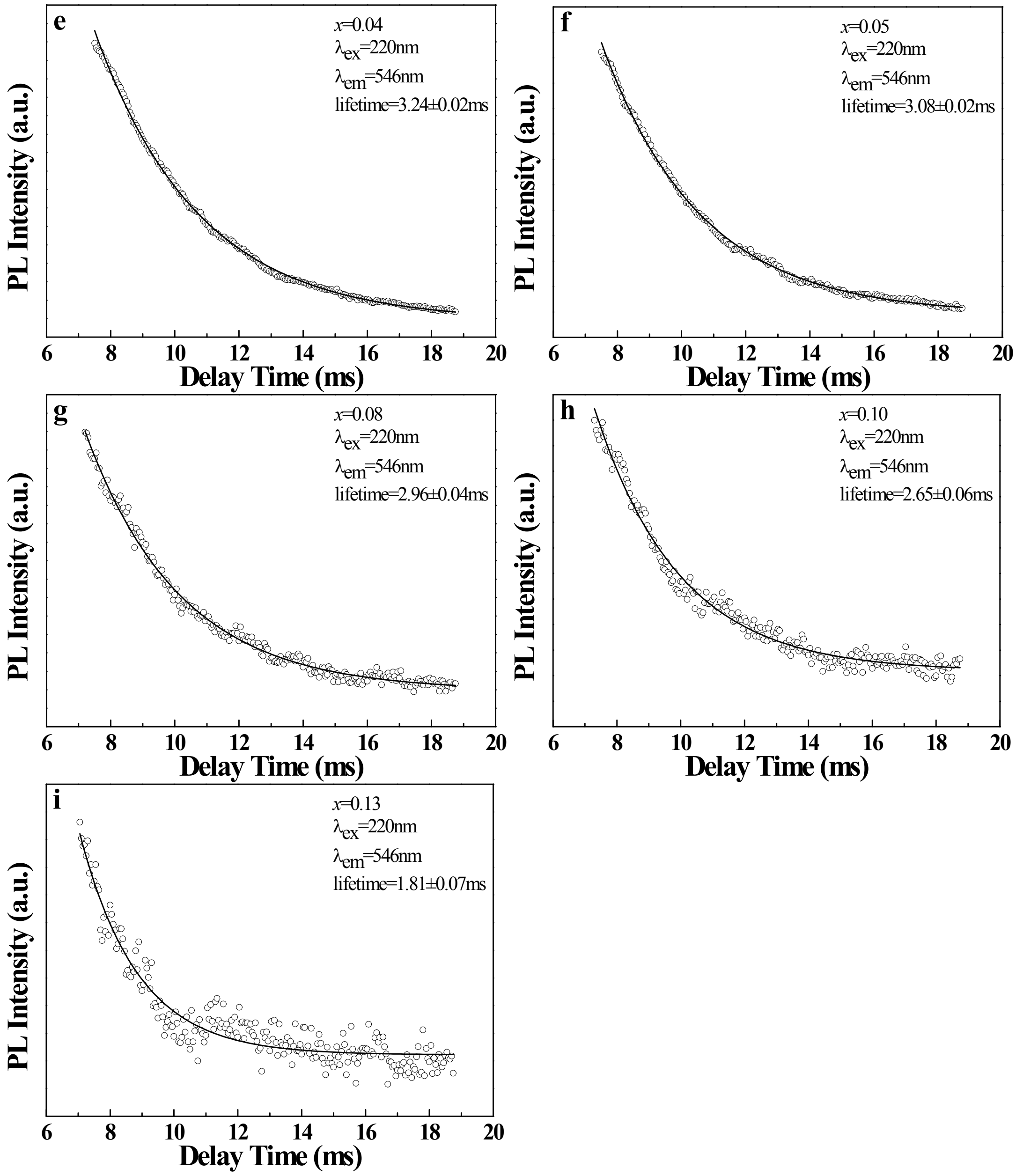


Fig. S7 Fluorescence decay curves for the 546-nm emission of $(Y_{0.98\text{-}x}Tb_{0.02}Eu_x)PO_4$ calcined at 1000 °C for 2 h.

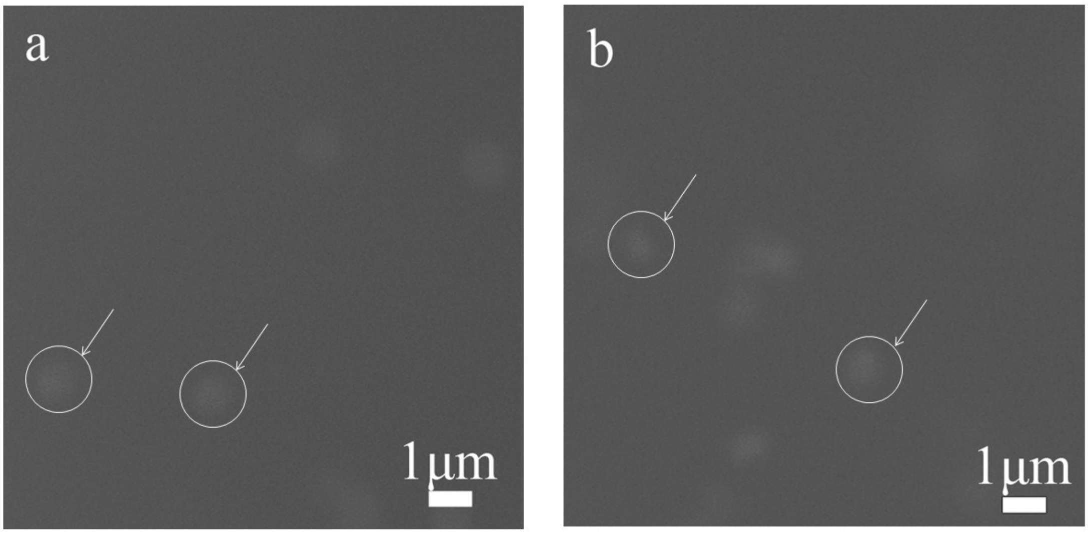


Fig. S8 FE-SEM micrographs showing morphology of the polymer film with (a) $(Y_{0.95}Eu_{0.05})PO_4{\cdot}nH_2O$ and (b) $(Y_{0.95}Eu_{0.05})PO_4$ spheres as fillers. The white objects pointed by arrows are the oxide spheres. As most of the spheres are buried in the interior of PVA, only those at or close to the film surface are unambiguously identifiable.