SUPPORTING INFORMATION

Deep tissue imaging with highly fluorescent NIR nanocrystals after systematic host screening

Fabian H.L. Starsich[1,†], Pascal Gschwend[1,†], Anton Sergeyev[2], Rachel Grange[2] and Sotiris E. Pratsinis[1,]*

[1]Particle Technology Laboratory, Institute of Process Engineering, Department of Mechanical and Process Engineering, ETH Zurich, Sonneggstrasse 3, CH-8092 Zurich, Switzerland

[2]Optical Nanomaterials Group, Institute for Quantum Electronics, Department of Physics, ETH Zürich, Auguste-Piccard-Hof 1, CH-8093 Zurich, Switzerland

[†]Authors contributed equally to this work

*Corresponding author:
Sotiris E. Pratsinis; Tel.: +41 44 632 31 80; fax: +41 44 632 15 95; e-mail: sotiris.pratsinis@ptl.mavt.ethz.ch

14.09.2017

Submitted to:

Chemistry of Materials

and revised

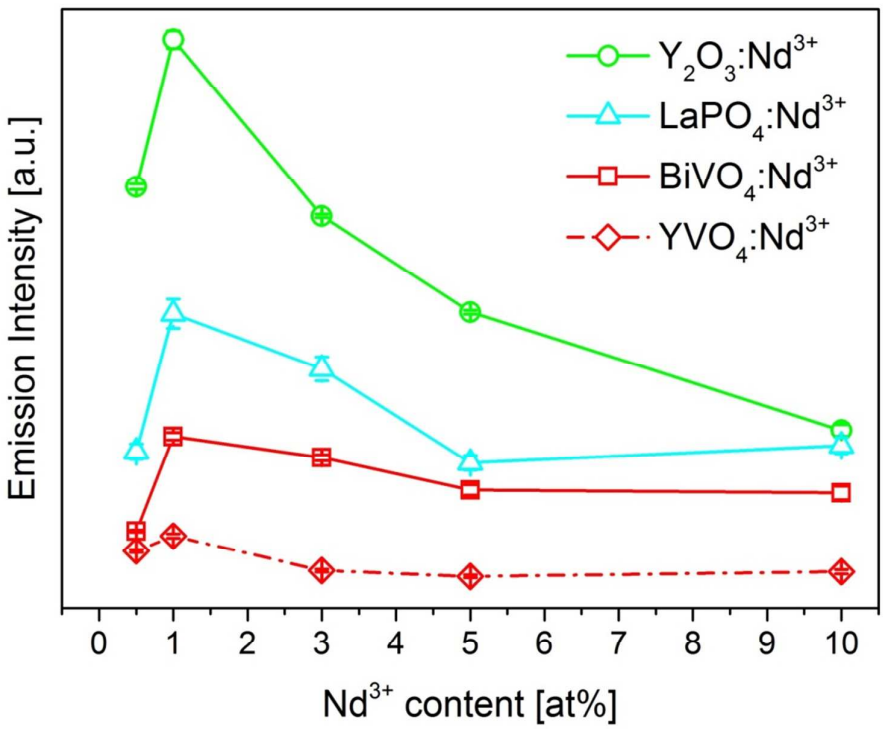

Figure S1: *Integrated emission of the $^4F_{9/2} \rightarrow {}^4I_{3/2}$ transition of Nd^{3+} (850-1000 nm) as a function of doping content for three different particles. The total nanoparticle mass was kept constant.*

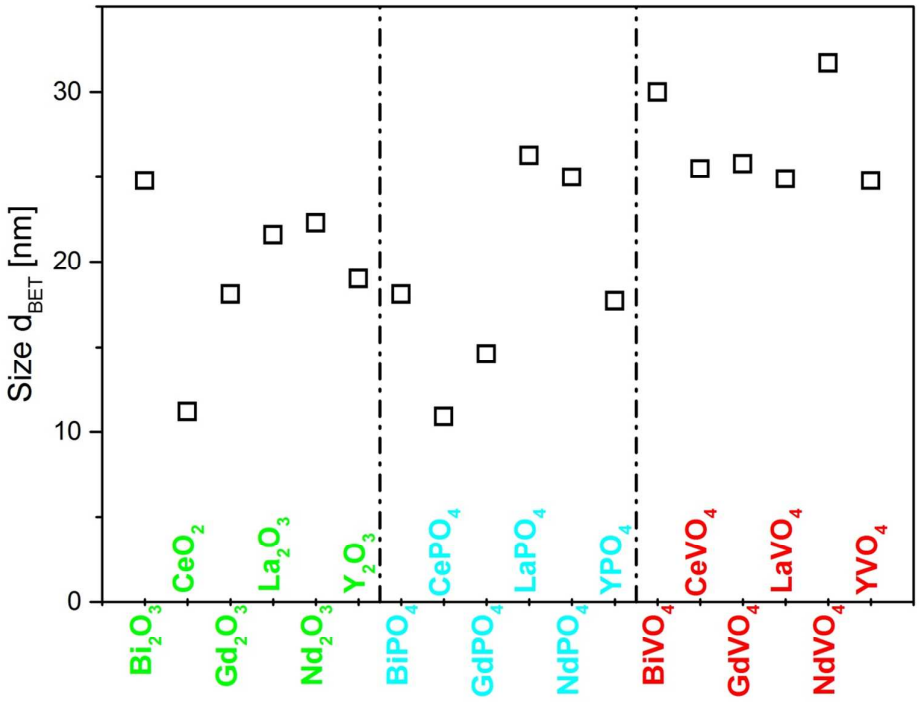

Figure S2: *Primary particle sizes (d_{BET}) of as-prepared Nd-doped (1 at%) particles*

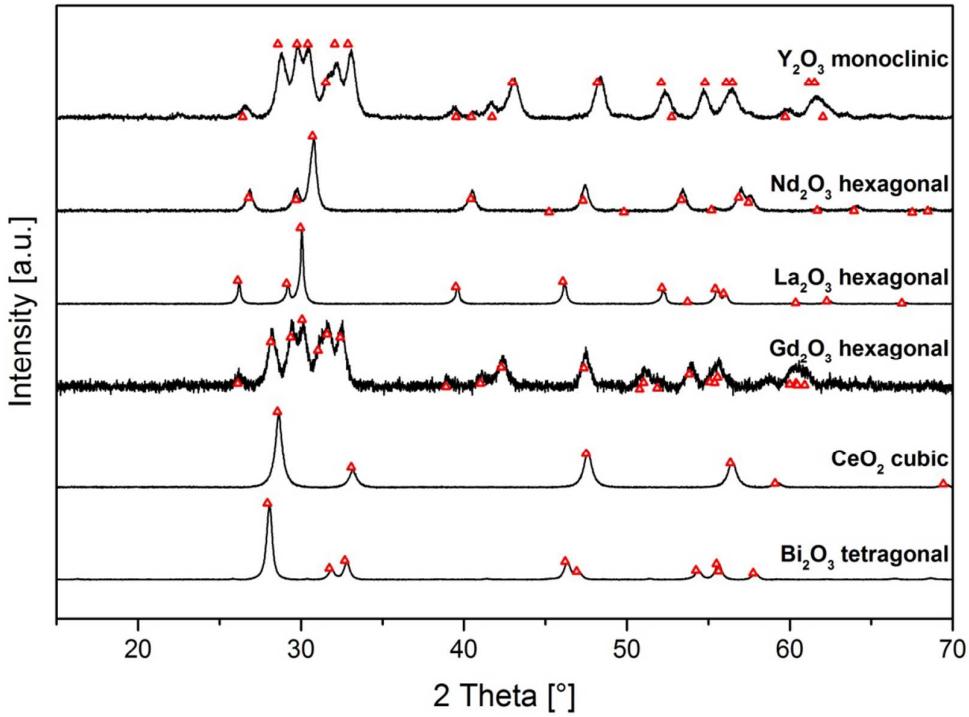

Figure S3: *XRD spectra of as-prepared oxides*

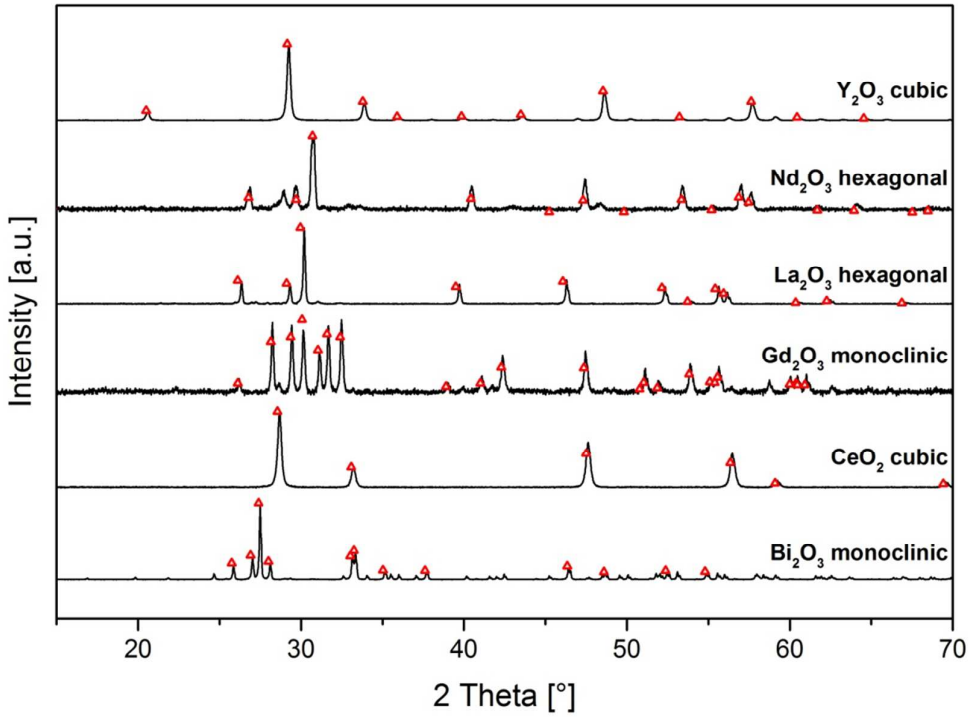

Figure S4: *XRD spectra of annealed oxides*

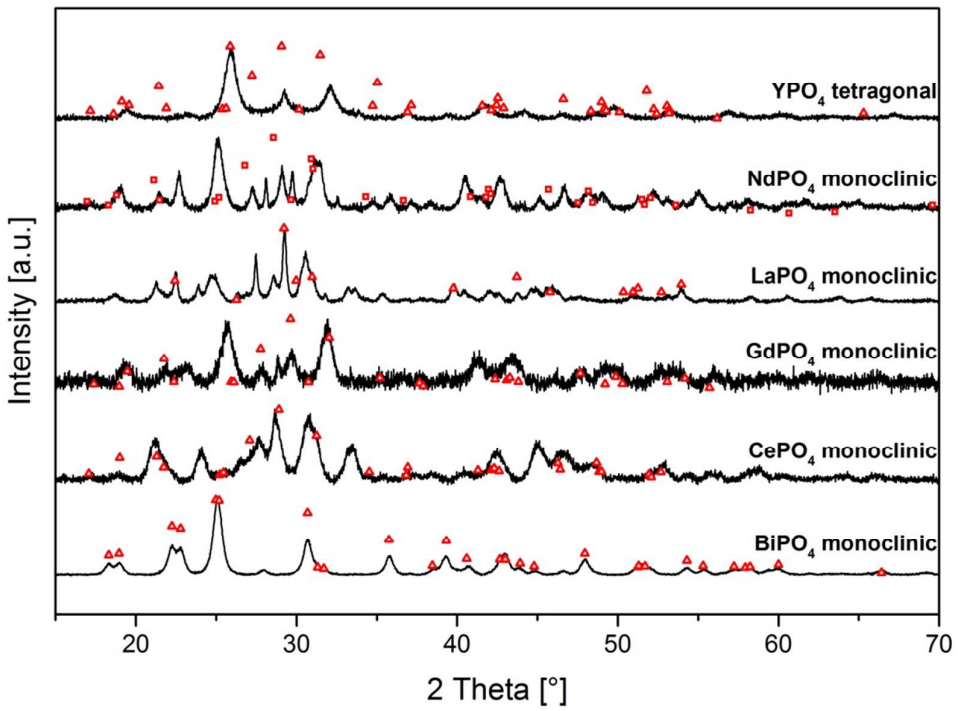

Figure S5: *XRD spectra of as-prepared phosphates*

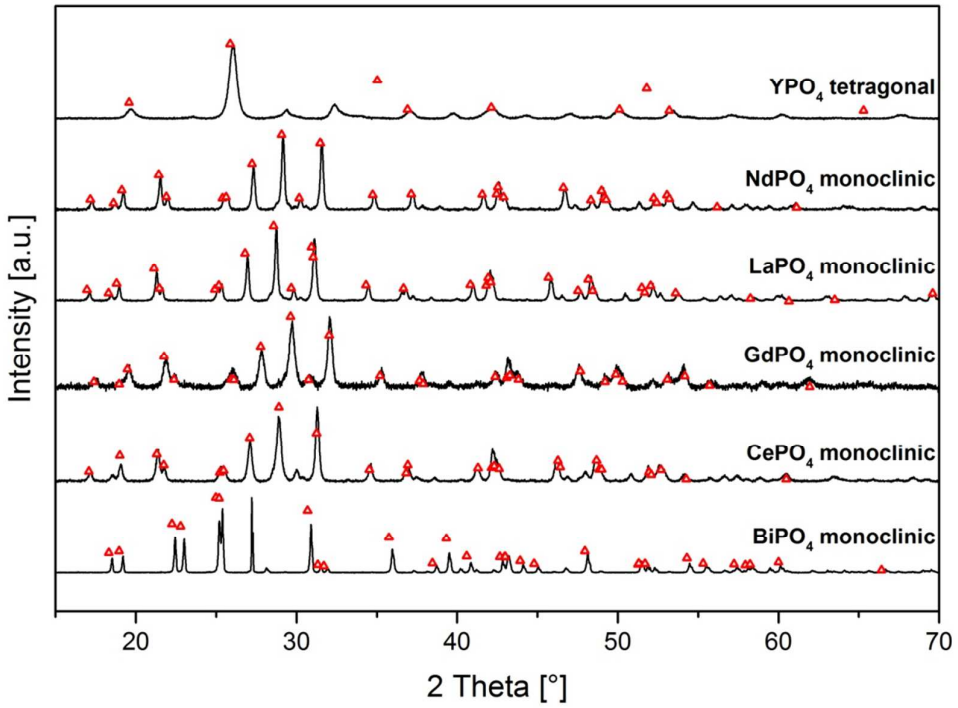

Figure S6: *XRD spectra of annealed phosphates*

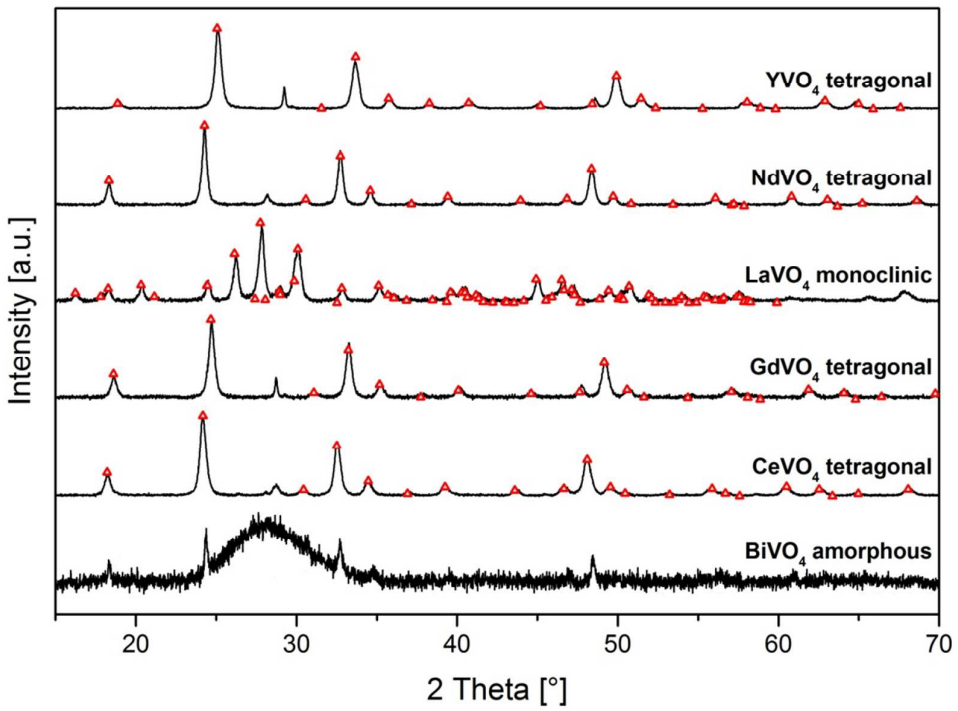

Figure S7*: XRD spectra of as-prepared vanadates*

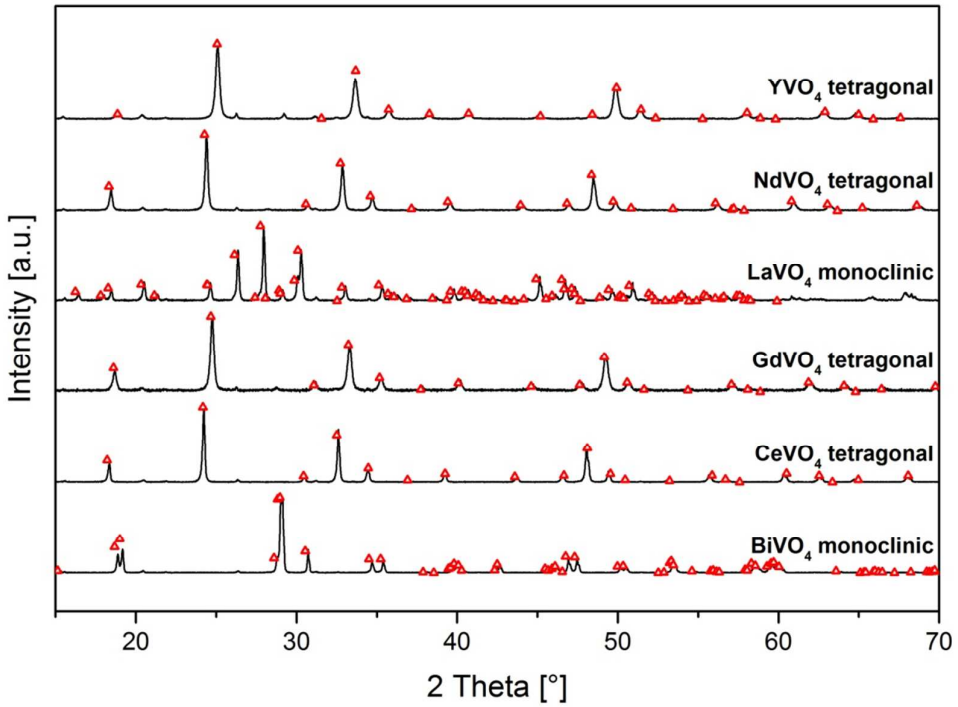

Figure S8*: XRD spectra of annealed vanadates*

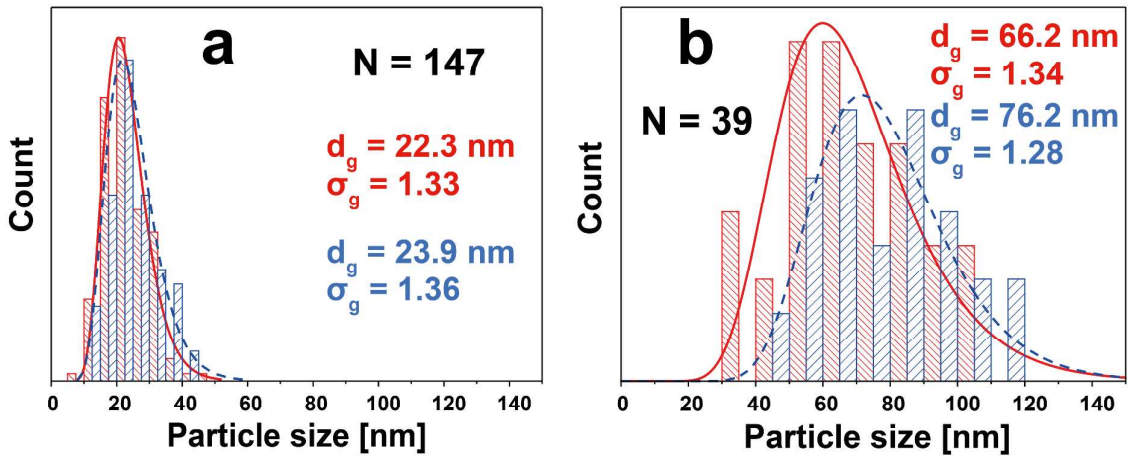

Figure S9: *Primary particle size (small (solid line) and large (broken line) axes) distributions and the corresponding geometric average diameters, d_g, and standard deviations, σ_g, as determined by image analysis of (a) as-prepared and (b) annealed $BiVO_4:Nd^{3+}$ nanoparticles.*

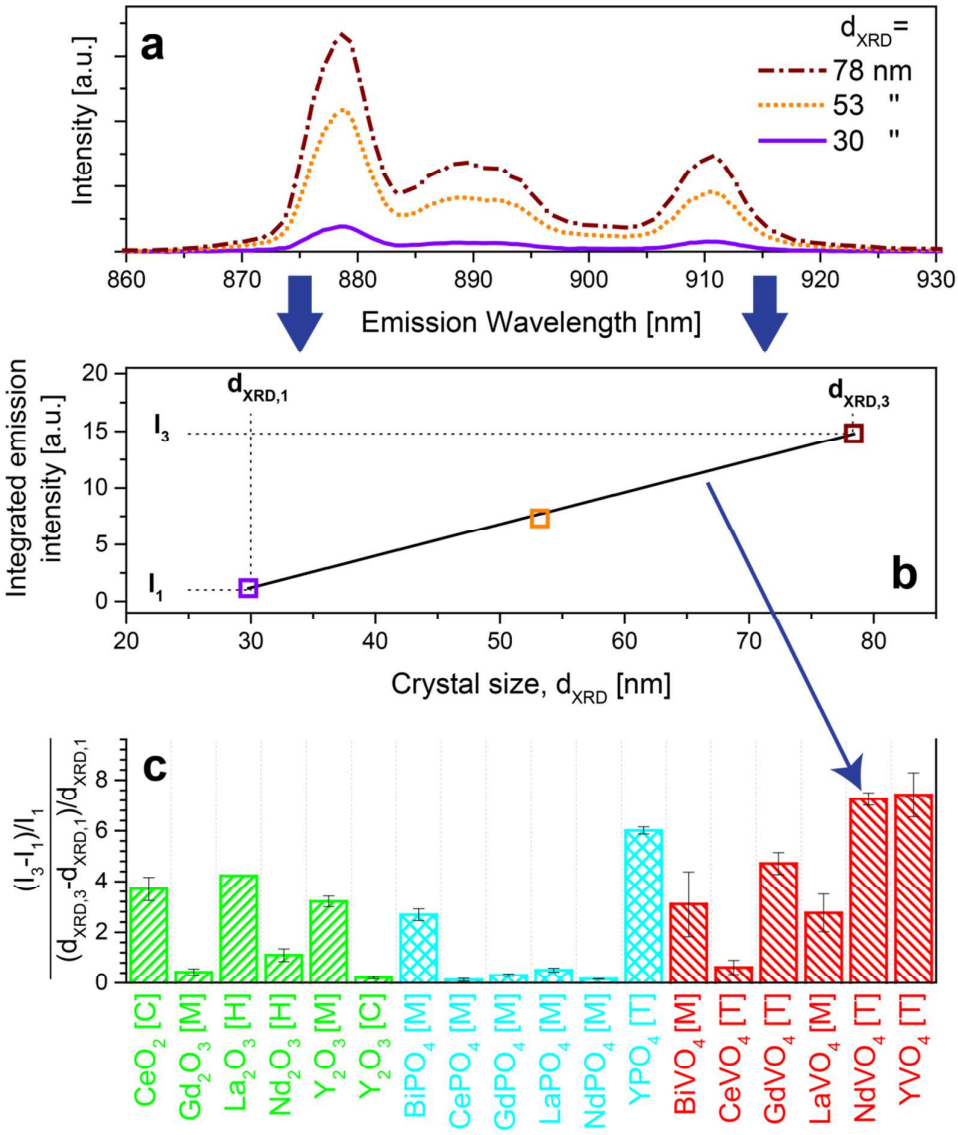

Figure S10: *(a) Emission spectra of $NdVO_4$ with d_{XRD} = 30, 53 and 78 nm. (b) The integrated emission intensity (850-1000 nm) as a function of crystal size (d_{XRD}) together with a linear fit. (c) Slope of the linear fits as shown in (b) for all host crystals using:*

$$Slope = \frac{\frac{I_3 - I_1}{I_1}}{\frac{d_{XRD,3} - d_{XRD,1}}{d_{XRD,1}}}$$

The values were normalized to remove differences in absolute emission intensity and be able to compare the relative change of integrated emission intensity with crystal size.

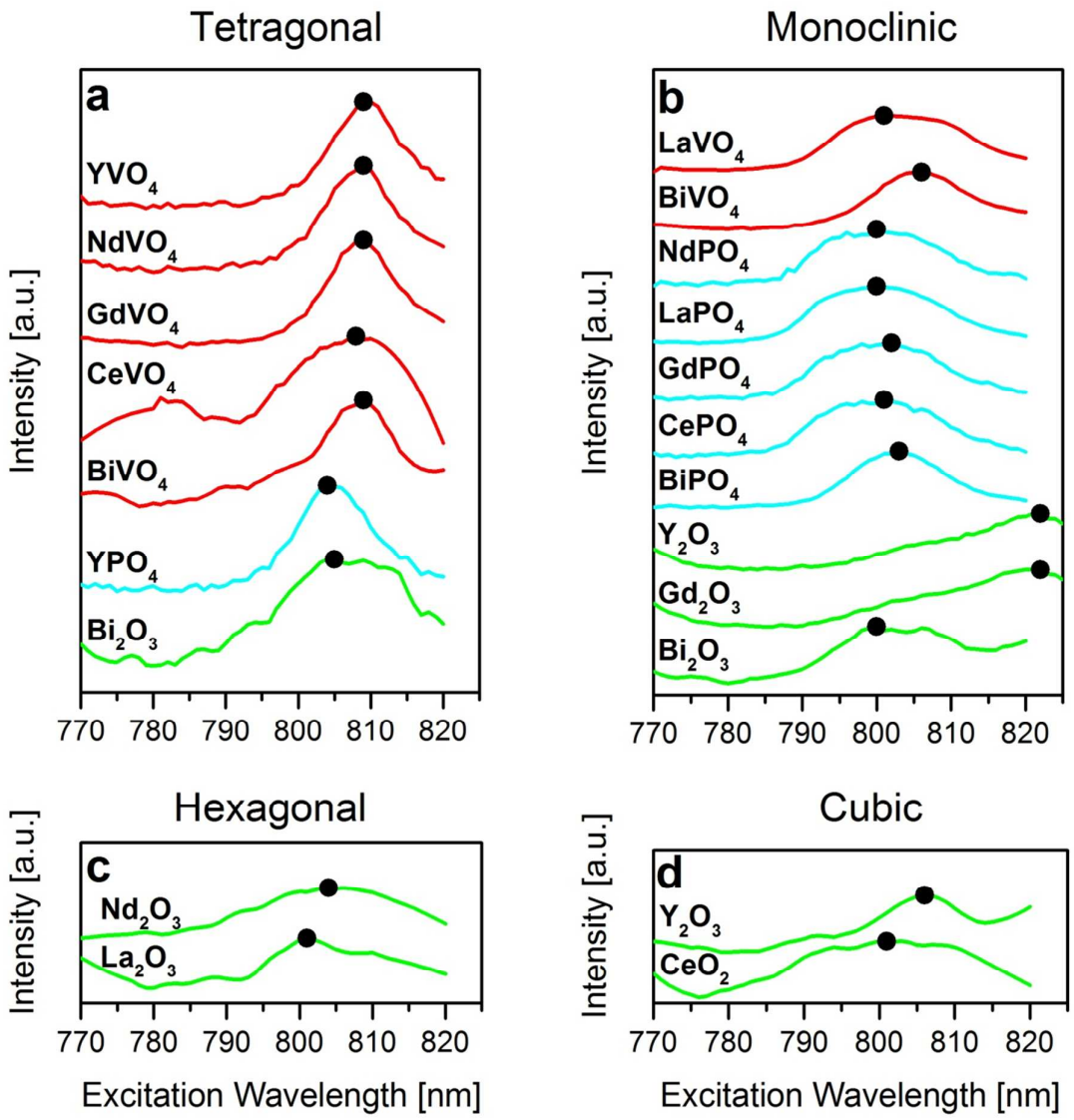

Figure S11*: Excitation spectra monitoring the integrated emission from 850-1000 nm. The optimized excitation wavelength (black circles), which is not dependent on the particle size,*[40,41] *was used to scale the emission intensity gathered under excitation from the 808 nm laser diode.*

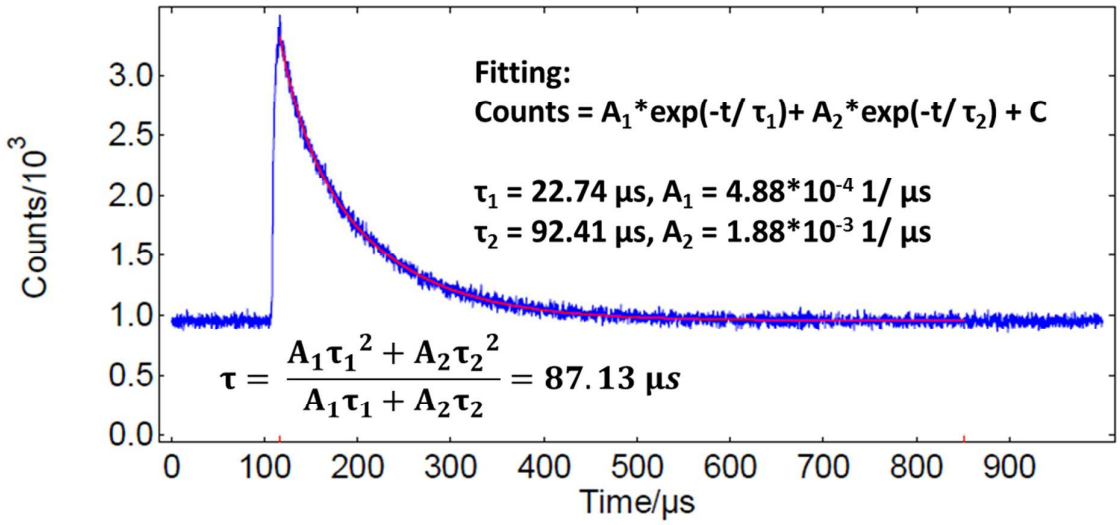

Figure S12: *Lifetime measurement of $BiVO_4$:Nd^{3+} in powder form. Inset shows parameters of double exponential fit and calculation of average lifetime.*

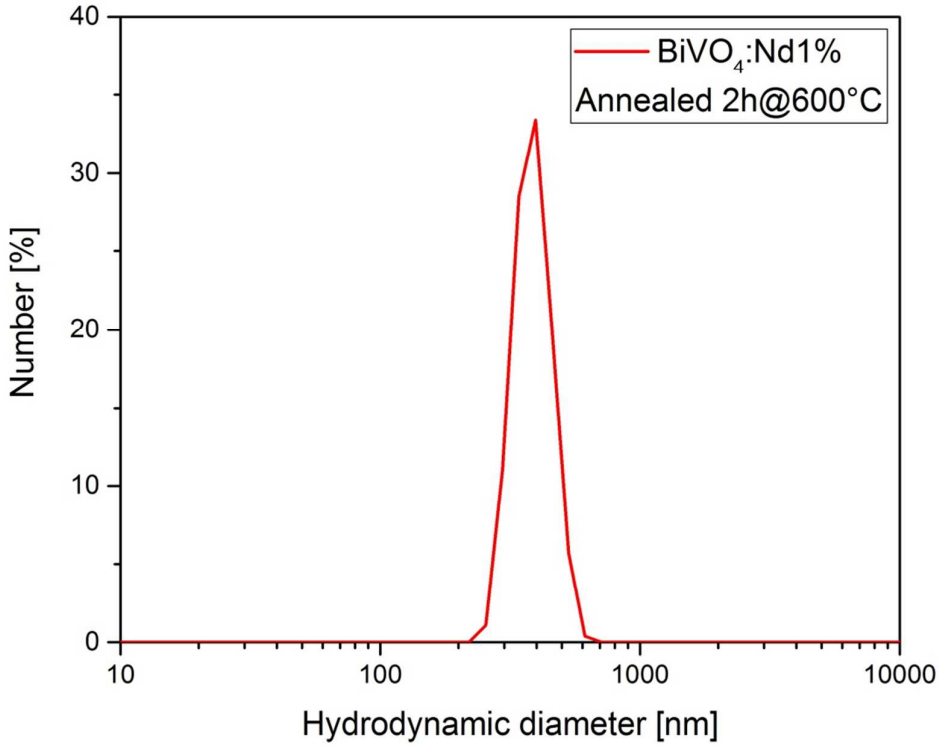

Figure S13: *Hydrodynamic size distribution of bare, unfunctionalized $BiVO_4$:Nd (annealed 2 hours at 600°C) measured by dynamic light scattering. The suspension was prepared at a particle concentration of 0.1 mg mL^{-1} of PBS buffer solution. The measurement was performed immediately after sonication.*

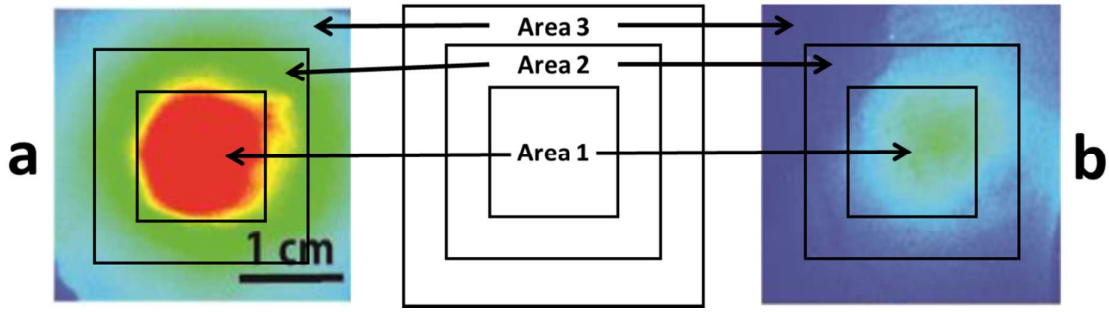

Figure S14: *Exemplary quantification of fluorescence by $BiVO_4:Nd^{3+}$ in Figure 4c at 3 (a) and 15 mm (b) depth.*

Table S1: *Average and integrated intensities for each boxed area in Figure S14 that were used to obtain the data points in Figure 4c.*

	Area (# pixel)	Average intensity	Integrated intensity
Area 1	3721	233.96	870’593
Area 2	6480	127.83	828’319
Area 3	9963	74.96	746’972
Total	**20’164**		**2’445’884**
Background	20’164	7.02	141’675
Total - Background			**2’304’209**

	Area (# pixel)	Average intensity	Integrated intensity
Area 1	3721	60.68	225’800
Area 2	6480	38.26	247’932
Area 3	9963	28.16	280’600
Total	**20’164**		**754’332**
Background	20’164	5.17	104’297
Total - Background			**650’035**

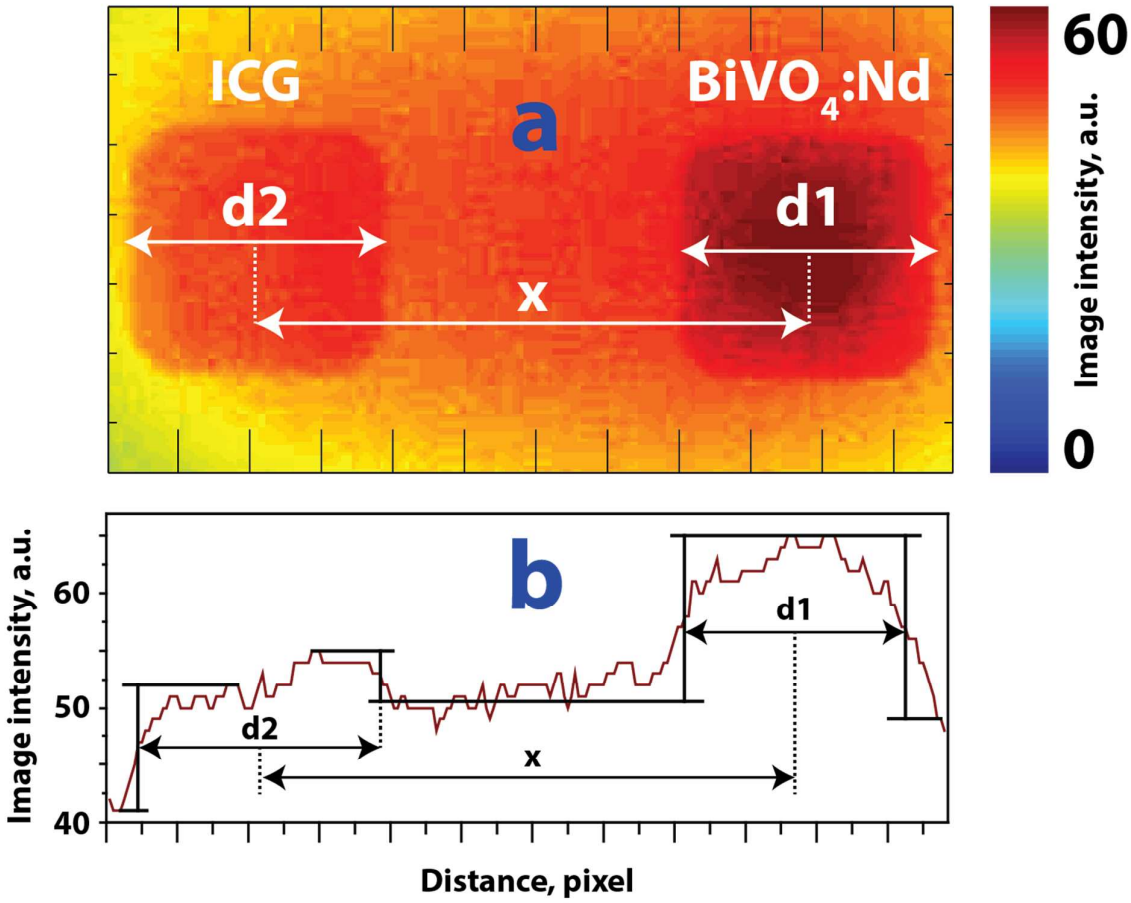

Figure S15: *(a) Initial NIR-fluorescence images of surgical dye ICG (left) and $BiVO_4:Nd^{3+}$ (right) patterned in a square, through 5 mm of optical phantom under tissue-friendly 808 nm excitation (0.2 W/cm^2). (b) Intensity along the x-axis through the center of the squared patterns.*

Pattern (contrast enhanced area) edges were defined as the average intensity between the maximum within the contrast enhanced area and adjacent background. This further led to the exact location of the pattern center (halfway between the edges), pattern widths (d1 and d2) and distance (x) between the two patterns (ICG and $BiVO_4:Nd^{3+}$) in pixels. As the distance x is also known in µm it was used to convert all other distances. The pattern widths were thereafter compared to the actual widths and the resolution was defined as the difference (ICG: 77 µm, $BiVO_4:Nd^{3+}$: 119 µm).

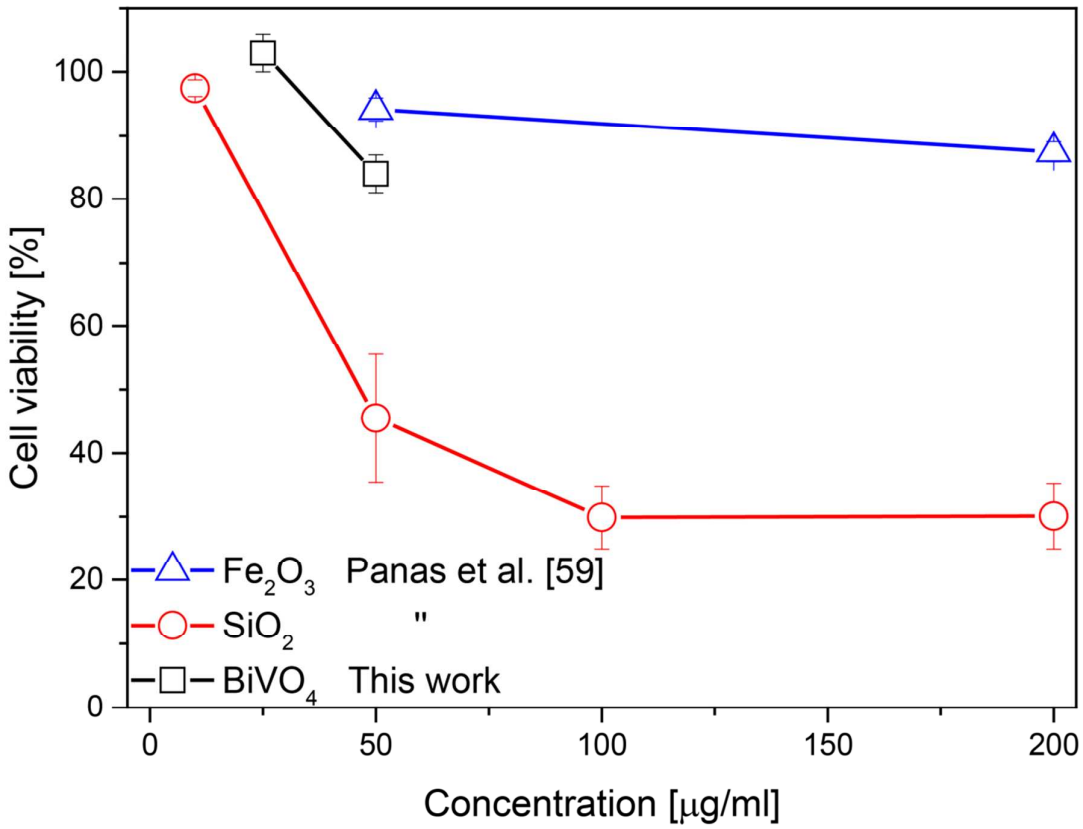

Figure S16: *Cytotoxicity of $BiVO_4:Nd^{3+}$ nanoparticles tested with murine macrophages (RAW 264.7). Values from Panas et al.[59] were added as comparison.*

1 ***Table S2**: Annealing conditions for all flame-made fluorescent nanoparticles (oxides, phosphates,*
2 *vanadates)*

Material	Temperature [°C]	Duration [h]	d_{XRD} [nm]	Crystal structure
Bi_2O_3	as-prepared	-	24.3	Tetragonal
	500	4	46.7	Monoclinic
	600	1	52.8	Monoclinic
CeO_2	as-prepared	-	17.7	Cubic
	800	2	23.2	Cubic
	1000	2	45.9	Cubic
Gd_2O_3	as-prepared	-	15.7	Monoclinic
	800	2	28.5	Monoclinic
	1000	2	79.8	Monoclinic
La_2O_3	-	-	37.2	Hexagonal
	800	2	41.2	Hexagonal
	900	2	47.6	Hexagonal
Nd_2O_3	as-prepared	-	18.4	Hexagonal
	800	2	36.6	Hexagonal
	1000	2	86.9	Hexagonal
$Y_2O_3^*$	as-prepared	-	11.3	Monoclinic
	as-prepared	-	17.3	Monoclinic
	800	2	23.0	Monoclinic
$Y_2O_3^*$	as-prepared	-	29.5	Cubic
	1000	2	48.0	Cubic
	1000	2	119.2	Cubic
$BiPO_4$	as-prepared	-	17.8	Monoclinic
	500	4	21.2	Monoclinic
	600	2	27.2	Monoclinic
$CePO_4$	as-prepared	-	-	Monoclinic
	600	2	11.0	Monoclinic
	800	2	22.5	Monoclinic
	1000	2	42.4	Monoclinic
$GdPO_4$	as-prepared	-	-	Monoclinic
	800	2	14.1	Monoclinic
	900	2	16.0	Monoclinic
	1000	2	27.5	Monoclinic

$LaPO_4$	as-prepared	-	-	Monoclinic
	800	2	27.2	Monoclinic
	1000	2	53.8	Monoclinic
	1200	2	81.9	Monoclinic
$NdPO_4$	as-prepared	-	-	Monoclinic
	800	2	28.8	Monoclinic
	900	2	31.6	Monoclinic
	1000	2	98.6	Monoclinic
YPO_4	as-prepared	-	-	Tetragonal
	900	2	18.6	Tetragonal
	1000	2	20.8	Tetragonal
	1200	2	33.0	Tetragonal
$BiVO_4$	as-prepared	-	-	Amorphous
	300	2	26.2	Tetragonal
	500	4	38.1	Monoclinic
	600	1	43.5	Monoclinic
	600	2	62.3	Monoclinic
$CeVO_4$	as-prepared	-	22.6	Tetragonal
	600	2	71.3	Tetragonal
	600	4	101.7	Tetragonal
$GdVO_4$	as-prepared	-	24.2	Tetragonal
	600	2	42.1	Tetragonal
	600	4	53.3	Tetragonal
$LaVO_4$	as-prepared	-	24.8	Monoclinic
	600	2	64.1	Monoclinic
	600	4	103.1	Monoclinic
$NdVO_4$	as-prepared	-	29.8	Tetragonal
	600	2	53.2	Tetragonal
	600	4	78.4	Tetragonal
YVO_4	as-prepared	-	22.9	Tetragonal
	600	2	33.7	Tetragonal
	600	4	37.6	Tetragonal

Missing d_{XRD} values are due to bad match with reference spectra. *Y_2O_3 was produced with various flame conditions and different precursor solvents to achieve monoclinic or cubic crystal phase[58].