Supplementary information

Efficient and recyclable Nd^{3+}-doped $CoFe_2O_4$ for boosted visible light-driven photocatalytic degradation of Rhodamine B dye

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Chemicals

Several chemicals, e.g., $Co(NO_3)_2 \cdot 4H_2O$ (98.0%), $Nd(NO_3)_3 \cdot 6H_2O$ (99.0%), $Fe(NO_3)_3 \cdot 9H_2O$ (98.0%), and urea $CO(NH_2)_2$ (99.0%) in this work were purchased from Merck, USA.

Characterization

XRD patterns were conducted on the D8 Advance diffractometer (Brucker, Madison, WI, USA) with the CuKα radiation (λ = 1.5406 Å) beams as excitation sources.

The particle morphology and size of the samples were recorded on SEM technique on a multi-purpose scanning electron microscope JSM-6510 (JEOL/EO, Tokyo, Japan) equipped with energy dispersive X-ray (EDX) spectroscopy.

The optical absorption characterization of the photocatalysts were determined using UV-Vis DRS on the Hitachi U-4100 spectrophotometer (Hitachi, Kyoto, Japan) in the wavelength range of 200–900 cm^{-1}.

The N_2 adsorption/desorption isotherms for surface area and pore distribution measurements were determined using Brunauer–Emmett–Teller (BET) and Barrett–Joyner–Halenda (BJH) methods, respectively and recorded on the Micromeritics TriStar 3000 V6.07 (Micromeritics Inc., Norcross, GA, USA).

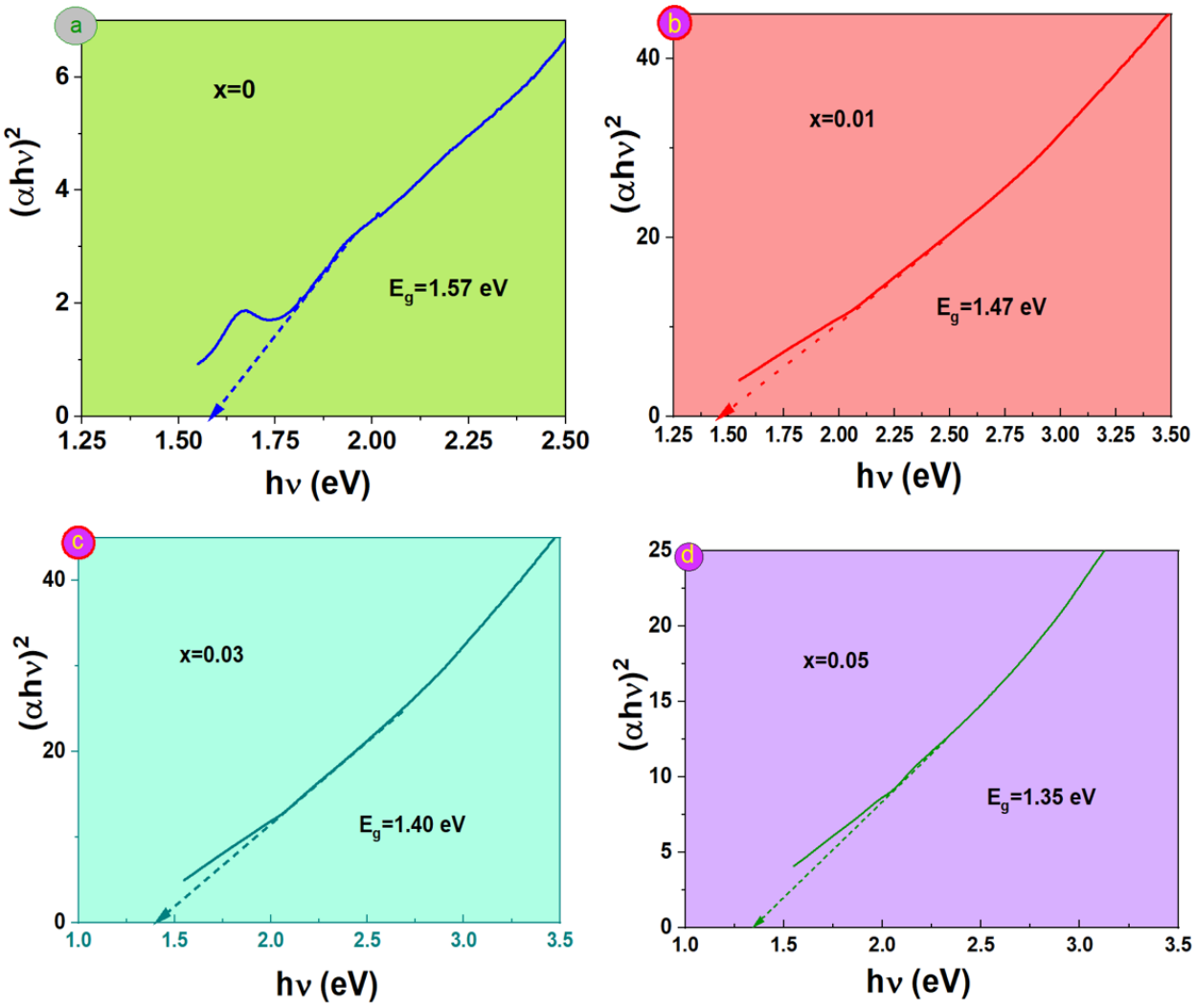

Fig. S1. UV–Vis diffuse reflectance spectra with Tauc plots of $(\alpha h\nu)^2$ against photon energy ($h\nu$) of (a) $CoFe_2O_4$, (b) $CoNd_{0.01}Fe_{1.99}O_4$, (c) $CoNd_{0.03}Fe_{1.97}O_4$, and (d) $CoNd_{0.05}Fe_{1.95}O_4$ catalysts.

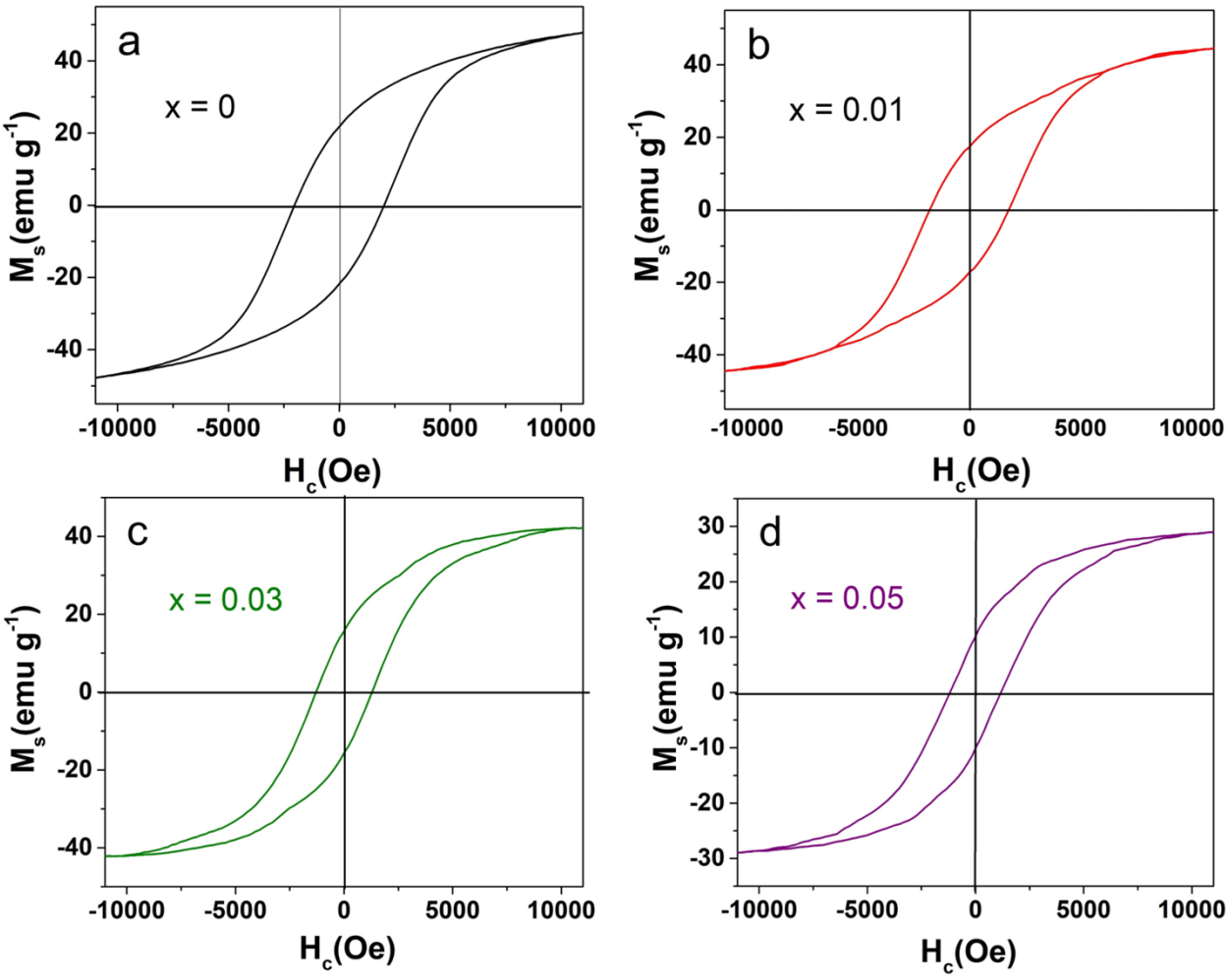

Fig. S2. Magnetic properties of (a) $CoFe_2O_4$, (b) $CoNd_{0.01}Fe_{1.99}O_4$, (c) $CoNd_{0.03}Fe_{1.97}O_4$, and (d) $CoNd_{0.05}Fe_{1.95}O_4$ catalysts.

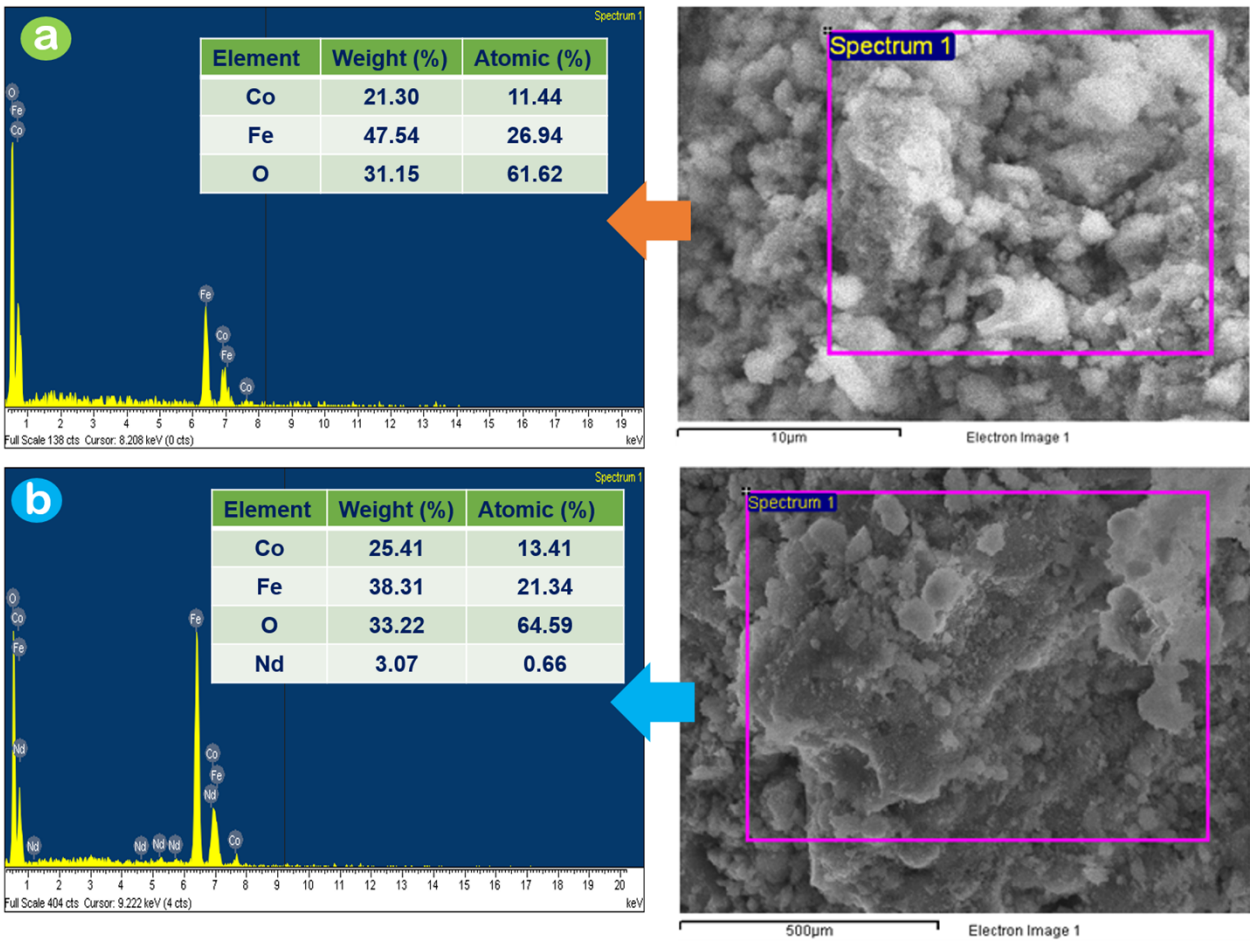

Fig. S3. Energy-dispersive X-ray spectroscopy analysis and chemical composition of (a) $CoFe_2O_4$, (b) $CoNd_{0.05}Fe_{1.95}O_4$ catalysts.

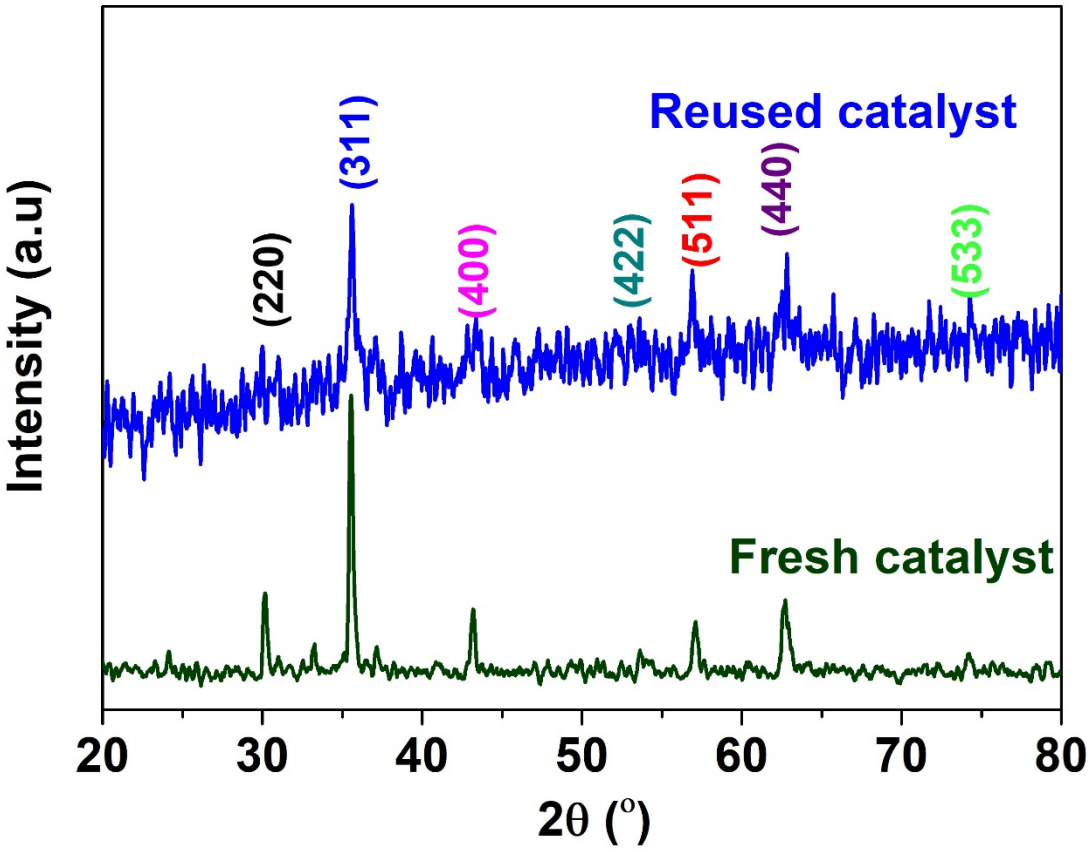

Fig. S4. The XRD patterns for fresh and reused $CoNd_{0.05}Fe_{1.95}O_4$ catalysts.

Table S1. The angle value (2θ) at lattice plane (331), particle size (r), typical FTIR absorbance bands of Nd–O bonds for tetrahedral sites (ν_1) and octahedral sites (ν_2) of $CoNd_xFe_{2-x}O_4$ (x = 0, 0.01, 0.03, 0.05) catalysts.

No	Catalyst	2θ (°)	r (nm)	ν_1 (cm^{-1})	ν_2 (cm^{-1})
1	$CoFe_2O_4$	35.27	14.35	551.6	424.3
2	$CoNd_{0.01}Fe_{1.99}O_4$	35.35	19.05	582.5	474.5
3	$CoNd_{0.03}Fe_{1.97}O_4$	35.51	26.74	590.2	482.2
4	$CoNd_{0.05}Fe_{1.95}O_4$	35.60	29.14	591.0	484.5

Table S2. Textual properties of $CoNd_xFe_{2-x}O_4$ (x = 0, 0.05) catalysts.

Surface property	$CoNd_xFe_{2-x}O_4$ (x = 0)	$CoNd_xFe_{2-x}O_4$ (x = 0.05)
Specific surface area	12.7 (m^2 g^{-1})	35.0 (m^2 g^{-1})
Total pore volume	0.099 (cm^3 g^{-1})	0.114 (cm^3 g^{-1})
Average pore width	32.8 (nm)	12.6 (nm)

Table S3. Degradation efficiency (H, %), degradation kinetic rate (k_1, min^{-1}), coefficient of determination (R^2) of removal of RhB dye using various $CoNd_xFe_{2-x}O_4$ (x = 0, 0.01, 0.03, 0.05) catalyst under visible light.

No	Catalyst	H (%)	$k_1 \cdot 10^3$ (min^{-1})	R^2
1	H_2O_2 only	12.9	0.7	0.99
2	Catalyst only	29.4	1.4	0.98
3	H_2O_2 + $CoFe_2O_4$	71.7	3.9	0.99
4	H_2O_2 + $CoNd_{0.01}Fe_{1.99}O_4$	75.9	4.1	0.99
5	H_2O_2 + $CoNd_{0.03}Fe_{1.97}O_4$	88.2	4.9	1.00
6	H_2O_2 + $CoNd_{0.05}Fe_{1.95}O_4$	94.7	5.3	0.96

Table S4. Degradation efficiency (H, %), degradation kinetic rate (k_1, min^{-1}), coefficient of determination (R^2) under $CoNd_{0.05}Fe_{1.95}O_4$ catalyst with and without addition of scavengers (e.g., ascorbic acid, ethylenediaminetetraacetic acid (EDTA), and isopropyl alcohol).

$ZnLa_{0.05}Fe_{1.95}O_4$	No scavenger	With ascorbic acid	With isopropyl alcohol	With EDTA
H (%)	93.7	61.6	52.1	49.8
$k_1 \cdot 10^3$ (min^{-1})	5.3	3.4	2.9	2.7
R^2	0.96	0.99	1.00	0.99

Note: [RhB] = 10 mg L^{-1}, Duration = 0–180 min, [H_2O_2] = 0.1 M, [catalyst] = 0.75 g L^{-1}, V = 100 mL, T = 25 ± 1 °C, agitation speed: 200 rpm, and pH 7 under LED visible light source.