Table S1 Detailed experimental, characterization, and photocatalytic data for the RE-doped metal oxide catalysts.

Host	Dopant	Conc. mol%	Synthesis	Band Gap (eV)	Surface Area (m²/g)	Dye Conc. (mg/L)	Volume (mL)	pH	k min^{-1}	PL	EIS	ESR	XPS	Scavenger	TOC	AQY	Real WW	Stability (cycles)	Leaching	Mech. Confidence	Ref
SnO_2	Ce^{3+}	3	Hydrothermal	2.65	62.62	10	10	7	0.0216	√	√	×	√	√	×	×	×	5	×	Direct	[1]
SnO_2	Ce^{3+}	4	Hydrothermal precipitation	3.11	-	20	100	-	0.5681	√	×	×	√	√	×	×	×	4	×	Partial	[2]
ZnO	Gd^{3+}/Nd^{3+}	1.5	Hydrothermal	3.04	-	20	70	-	-	√	×	×	×	×	×	×	×	-	×	Partial	[3]
CeO_2	Y^{3+}	5	Sol-gel	3.12	-	5	50	-	-	×	×	×	√	×	×	×	×	-	×	Partial	[4]
ZnO	Ce^{3+}	1	Electrospinning + Hydrothermal	-	-	10	-	7	-	√	×	×	√	×	×	×	×	3	×	Partial	[5]
ZnO: TiO_2	Ce^{3+}	1	Sol-gel	2.62	-	20	50	6.9	-	√	√	√	√	√	×	×	×	-	×	Direct	[6]
TiO_2-ZnO	Yb^{3+}/Er^{3+}	1Yb/ 1Er	Sol-gel	2.92	-	4	200	6.8	1.8562	√	√	√	√	√	√	×	×	4	×	Direct	[7]
ZnO	Er^{3+}	3	Sol-gel	3.24	12.4	10	100	-	0.0305	√	×	×	√	√	√	×	×	3	×	Direct	[8]
ZnO	Er^{3+}	3	Chemical precipitation	3.22	24.05	10	100	7	0.03538	√	√	×	√	√	×	×	×	4	×	Direct	[9]
TiO_2	Eu^{3+}	6	Solvothermal	3.43	-	40	100	3	-	√	×	×	√	√	×	×	×	4	×	Partial	[10]
TiO_2	Eu^{3+}	0.1	Sol-gel	3.5	-	10	50	3.5	0.036	√	√	×	√	√	√	×	×	-	×	Direct	[11]
TiO_2	Gd^{3+}	1.5	Hydrothermal	3.06	174	5	25	-	-	√	√	×	√	√	√	×	×	4	×	Direct	[12]
ZnO	Gd^{3+}	7.5	Sol-gel combustion	3.07	-	10	50	-	0.00723	×	√	×	×	×	×	×	×	5	×	Partial	[13]
ZnO-	Gd^{3+}	0.6	Co-precipitation	2.90	-	20	100	-	0.01923	√	×	×	√	√	×	×	×	-	×	Partial	[14]
TiO_2	La^{3+}	2	Sol-gel	2.99	128	10	100	6	0.0180	√	×	×	√	√	√	×	×	4	×	Partial	[15]

TiO_2	La^{3+}	1.5	Solution-combustion	2.7	-	30	100	-	0.048	√	×	×	√	×	×	×	×	5	×	Partial	[16]
WO_3	La^{3+}	3	Chemical precipitation	2.72	-	10	100	-	0.02075	√	×	×	√	√	√	×	×	4	×	Direct	[17]
ZnO	La^{3+}	2	Sol-gel	3.01	-	10	100	9	0.015	√	×	×	√	√	×	×	×	3	×	Partial	[18]
TiO_2	Nd^{3+}	3	Sol-gel ultrasonication	3.16	-	20	100	7	0.0786	√	×	×	√	×	×	×	×	5	×	Partial	[19]
ZnO	Nd^{3+}	0.1	Electrospinning-calcination	3.14	-	10	100	7	0.04780	√	×	×	√	√	√	×	×	5	×	Direct	[20]
ZnO	Nd^{3+}	4	Hydrothermal	3.00	-	20	100	8	0.0161	√	×	×	√	×	×	×	×	-	×	Partial	[21]
ZrO_2	Nd^{3+}	2	Co-precipitation	1.23	-	-	50	7	0.00944	√	√	×	√	√	×	×	×	3	×	Direct	[22]
TiO_2	Sm^{3+}	5	Photolysis	2.86	115	30	-	12	0.02094	√	√	×	√	√	√	×	×	5	×	Direct	[23]
ZnO	Sm^{3+}	5	Co-precipitation	3.09	-	10	75	-	0.21	√	×	×	√	√	√	×	×	5	×	Direct	[24]
ZnO	Sm^{3+}	1	Co-precipitation	-	-	10	25	-	0.01	√	√	×	√	√	×	×	×	4	×	Partial	[25]
ZnO	Sm^{3+}	10	Sol-gel	-	-	0.2	≈4.2	-	0.01	√	×	×	√	√	×	×	×	-	×	Partial	[26]
TiO_2	Ho^{3+}/ Yb^{3+}	1 Ho + 1Yb	Hydrothermal	3.15	-	5	100	-	0.01	√	×	×	√	√	×	×	×	-	×	Direct	[27]
TiO_2	Nd^{3+}/ Yb^{3+}	5Nd + 3Yb	Hydrothermal	3.03	-	10	60	-	0.02	√	√	×	√	√	×	×	×	-	×	Direct	[28]
ZnO	Yb^{3+}	1	Co-precipitation	3.33	-	20	-	6.3	-	√	×	√	√	√	√	×	×	4	√	Direct	[29]

Table S2 Comparison of the main synthesis routes represented in the reviewed rare-earth-doped metal oxide photocatalyst studies, including their principal advantages, limitations, and typical effects on morphology and structure.

Synthesis route	Principal advantages	Principal limitations	Typical influence on morphology/structure	Representative Ref.
Sol-gel	Good compositional control; relatively simple preparation; suitable for homogeneous dopant incorporation	Drying and calcination can affect particle growth; solvent use; aggregation may occur	Nanoparticle formation; particle size and crystallinity depend strongly on hydrolysis, drying, and calcination conditions	[15]
Hydrothermal	Controlled crystal growth; good crystallinity; morphology can be tuned through reaction conditions	Requires elevated temperature and pressure; batch operation can complicate scale-up	Can produce controlled crystalline morphologies and well-defined particle structures	[28]
Precipitation/co-precipitation	Simple, relatively low-cost, and suitable for preparing doped oxide nanoparticles	Particle size and dopant distribution can be sensitive to pH, precipitation rate, and aging	Generally, produces nanoparticles; aggregation and non-uniform dopant distribution may occur	[24]
Combustion	Rapid synthesis; relatively short processing time; can produce crystalline oxide powders	High reaction temperature; rapid combustion may limit control over particle growth and morphology	Fine particles can form, but particle growth and porosity depend strongly on fuel/oxidant ratio and calcination	[16]

Electrospinning-based	Enables formation of one-dimensional structures and continuous fibers	More complex equipment and processing; post-calcination is generally required	Produces nanofibers or other one-dimensional structures with morphology controlled by spinning and calcination conditions	[20]
Solvothermal	Allows controlled crystal growth in non-aqueous media and can provide tunable morphology	Requires organic solvents and elevated temperature/pressure; additional safety and processing considerations	Can produce well-defined crystalline morphologies depending on solvent and reaction conditions	[10]

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