

Fabrication of nanohybrids assisted by protein-based materials for catalytic applications

*Mingyue Liu,^{†a} Tao Yu,^{†b} Renliang Huang,^c Rongxin Su,^{*b,d,e} Wei Qi^{b,d} and Zhimin He^b*

^a School of Pharmaceutical and Chemical Engineering, Taizhou University, 1139 Shifu Avenue, Taizhou 318000, China

^b State Key Laboratory of Chemical Engineering, Tianjin Key Laboratory of Membrane Science and Desalination Technology, School of Chemical Engineering and Technology, Tianjin University, Tianjin 300072, P. R. China E-mail: surx@tju.edu.cn

^c School of Environmental Science and Engineering, Tianjin University, Tianjin 300072, P. R. China

^d Collaborative Innovation Center of Chemical Science and Engineering (Tianjin), Tianjin 300072, P. R. China

^e School of Marine Science and Technology, Tianjin University, Tianjin 300072, P. R. China

† These authors contributed equally to this work.

Table S1 The preparation and application of metal nanostructures templated by different proteins

Protein templates	Metal nanostructure	Synthesis condition	Function	Ref.
Apo-ferritin	Pd NPs	Soaking and chemical reduction (NaBH ₄)	Hydrogenation of alkenes	32, 86
Urease	Au NPs (8.9±1.6 nm)	Soaking and biomineralization	Catalytic reduction of p-nitroaniline	51
Silk-fibroin	Pd NPs	Soaking and chemical reduction (MeOH)	Highly chemoselective hydrogenation	68
Apo-ferritin	Au-Ag Alloy NPs (5.6-6.3 nm)	Soaking and biomineralization	Catalytic reduction of 4-NP	52
Cross-Linked Lysozyme Crystals	Au NPs (1.19-2.33 nm)	Soaking and biomineralization	Catalytic reduction of 4-NP	4
Cross-Linked Lysozyme Crystals	Au NPs, Ag NPs	Soaking and biomineralization	Catalytic reduction of 4-NP	7, 38
Procyanidin Grafted ESM	Ag NPs (2.19 nm)	Soaking and chemical reduction (procyanidin)	Catalytic reduction of 4-NP	8
Thiolated ESM	Au NPs (11.7±1.5 nm)	Chemical reduction (trisodium citrate)	Catalytic reduction of 4-NP	13
β-lactoglobulin fibrils	Au NPs, Pd NPs	Soaking and chemical reduction (NaBH ₄)	Catalytic reduction of 4-NP	23, 29, 46
β-lactoglobulin fibrils	Cu-Ag Alloy NPs, Cu-Ag-Au Alloy NPs	Soaking and chemical reduction (NaBH ₄)	Catalytic reduction of 4-NP	24
ESM	Au NPs, Ag NPs	Soaking and biomineralization	Catalytic reduction of 4-NP	26,85
Silk-fibroin	Au NPs (50-100 nm)	Soaking and chemical reduction (sulfonated polyaniline)	Catalytic reduction of 4-NP	69
Rhizopus oryzae mycelia	Pd NPs, Pt NPs, Ag NPs	Soaking and biomineralization	Catalytic reduction of 4-NP	71
Rhizopus oryzae protein extract	Au NPs (5-65 nm)	Soaking and biomineralization	Catalytic reduction of 4-NP	83
Apo-ferritin	Au NPs (2-17 nm)	Photochemical reduction (Na-citrate)	Catalytic reduction of 4-NP	84
Tobacco Mosaic Virus (TMV)	Ag NPs (2-9 nm)	Soaking and biomineralization	Catalytic reduction of 4-NP	42
TMV	Pd NPs (11.5 nm)	Soaking and chemical reduction (NaPH ₂ O ₂)	Dichromate reduction	37, 41
TMV	Pd NPs (1-2 nm)	Soaking and biomineralization	Dichromate reduction	3
Procyanidin grafted ESM	Pt/Pd NPs	Soaking and chemical reduction (NaBH ₄)	Dichromate reduction	27

Shewanella loihica PV-4	Pd NPs (4-10 nm)	Soaking and chemical reduction (Sodium formate)	Dichromate reduction	104	
Tannic Acid-Grafted ESM	Ag NPs (1-4 nm)	Soaking and biomineralization	Catalytic degradation of Azo Dyes	14	
Gum olibanum	Pd NPs (75.3±0.7 nm)	Soaking and biomineralization	Catalytic degradation of dye	49	
Apo-ferritin	Pd NPs	Soaking and chemical reduction (NaBH ₄)	Suzuki–Miyaura cross-coupling reaction	32	
Pyrococcus furiosus ferritin	Pd NPs (5±1 nm)	Soaking and biomineralization	Aerobic oxidations	33	
Natural silk	MnO ₂ NPs	Soaking and biomineralization	Aerobic oxidations	97	
Pd4 peptide	Pd NPs	Biomineralization	Stille Coupling Reaction	36	
Candida antarctica B lipase	Pd NPs	Soaking and chemical reduction (MeOH)	Suzuki–Miyaura reaction	50	
TMV	Pd NPs	Soaking and chemical reduction (NaPH ₂ O ₂)	Suzuki coupling reaction	40	
Rhizopus oryzae mycelia	Pd NPs, Pt NPs, Ag NPs	Soaking and biomineralization	Suzuki Coupling Reactions	71	
Apo-ferritin	Pt NPs (1-2 nm)	Soaking and chemical reduction (NaBH ₄)	Catalase and peroxidase activities	15, 112	88,
Apo-ferritin	CeO ₂ NPs (4.5 nm)	Dissociation–reconstruction	Artificial redox enzyme activity	16	
Heat shock protein cage	Pt NPs (2.2±0.7 nm)	Soaking and chemical reduction (dimethylamine borane complex)	Artificial hydrogenase activity	39	
ESM	NiCo ₂ O ₄ NPs (20-30 nm)	Soaking and chemical reduction (Urea)	Supercapacitors, Oxygen evolution reaction (OER) catalysis	25	
M13 phage	Au/Pt core/shell Nanowires (NWs)	Soaking and chemical reduction (ascorbic acid)	Electrocatalytic activity	30	
Insulin Amyloid Fibrils	Pt-Pd NPs	Soaking and biomineralization	High Electrocatalytic Activity	67	
ESM	Y ₂ O ₃ @Pd NPs	Soaking and biomineralization	Methanol oxidation reaction	87	
Bacteriophage P22	TiO ₂ NPs (~10 nm)	Soaking and biomineralization	Photocatalytic activity (degradation of methylene blue)	31	
Cowpea chlorotic mottle virus (CCMV)	β-TiO ₂ NPs	Soaking and biomineralization	Photocatalytic activity (degradation of methylene blue)	58	
ESM	NiO/CeO ₂ NPs	Soaking and biomineralization	Methane steam reforming	72	