

Supporting Information

Ru Nanoworms Loaded TiO₂ for Their Catalytic Performances toward CO Oxidation

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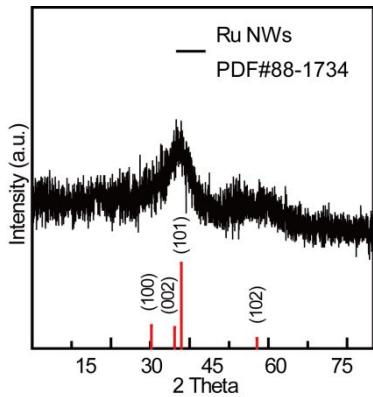


Figure S1 XRD patterns of the as-prepared Ru NWs.

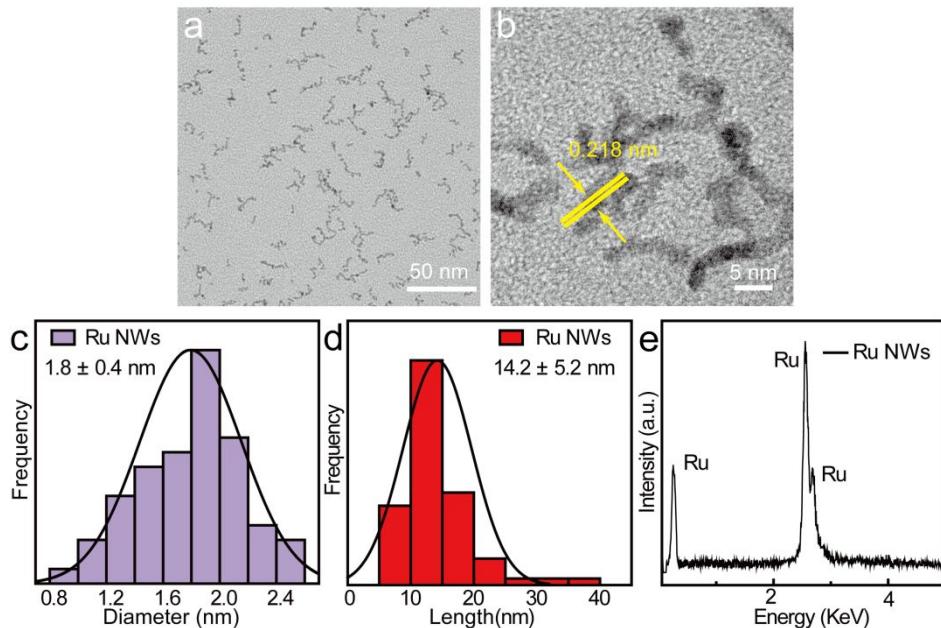


Figure S2. (a–e) Representative TEM, HRTEM, the size distribution including the diameter and the length, and the EDX spectrum taken on the SEM attachment of the as-prepared Ru NWs grown at 3 hours, respectively.

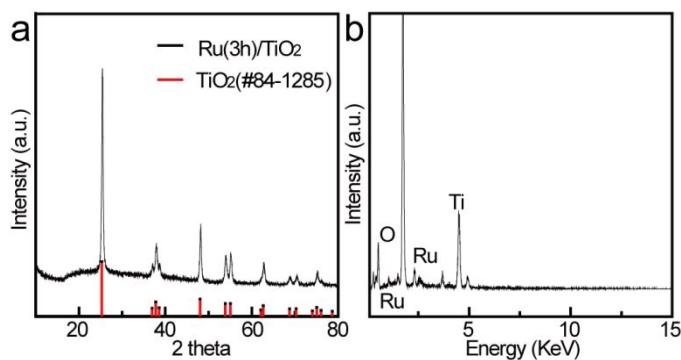


Figure S3. (a,b) XRD pattern and EDS spectrum of the obtained Ru NWs/TiO₂, respectively.

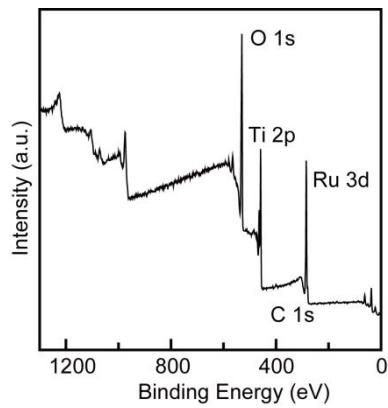


Figure S4. XPS spectrum of the Ru NWs/TiO₂ nanocatalysts.

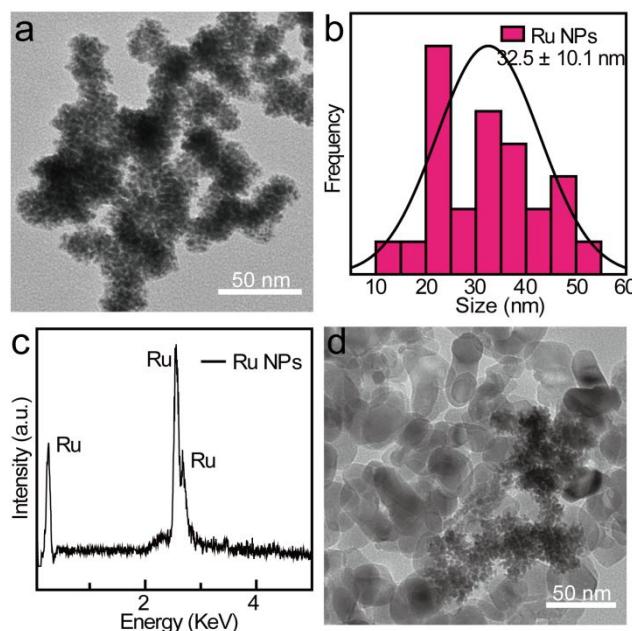


Figure S5. (a–c) TEM image, size distribution, and the EDX spectrum of the Ru NPs, respectively. (d) TEM image of the Ru NPs/TiO₂ nanostructures.

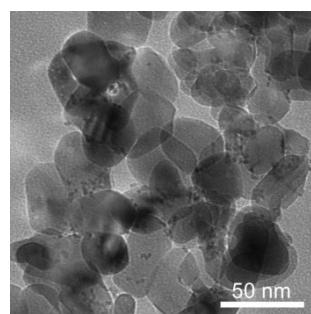


Figure S6. TEM images of the Ru NWs(3h)/TiO₂ nanostructure.

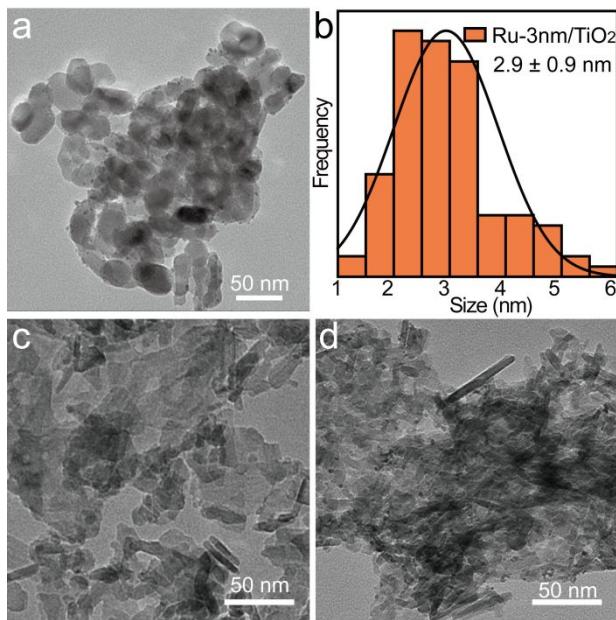


Figure S7. (a,b) Representative TEM image and size distribution of the Ru–3nm/TiO₂ nanostructures. The sample was synthesized using a wet-chemical method. Typically, deionized water (10 mL) was added into a centrifuge tube, followed by adding sequentially an aqueous RuCl₃ (0.1 M 360 µL) solution and TiO₂ (150 mg). The mixture was stirred magnetically at room temperature for 2 h. Then ice-cold aqueous NaBH₄ (0.1 M, 1.5 mL) was added and stirred at room temperature overnight. After centrifugation and washing with anhydrous ethanol, the Ru–3nm/TiO₂ nanostructures were dried under vacuum at 60°C for further use. (c,d) TEM images of Pure Al₂O₃ and Ru NWs/Al₂O₃ nanostructures, respectively.

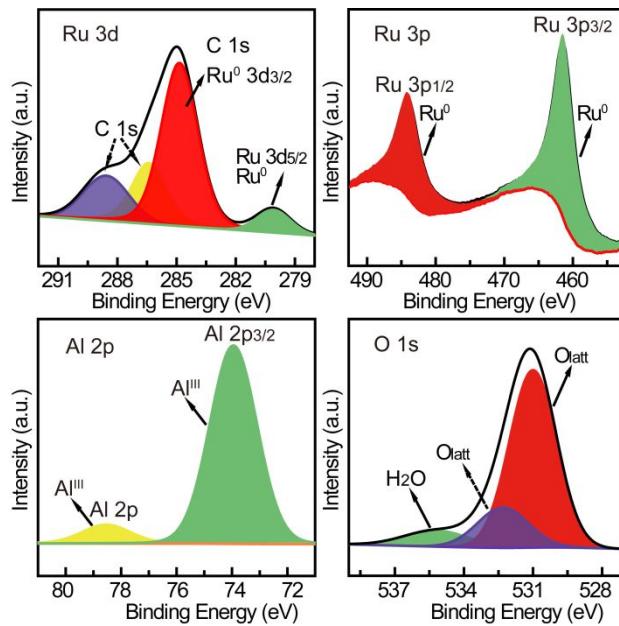


Figure S8 High-resolution XPS spectrum of C 1s and Ru 3d, Ru 3p, Ti 2p, and O 1s obtained from Ru NWs/Al₂O₃ sample, respectively.

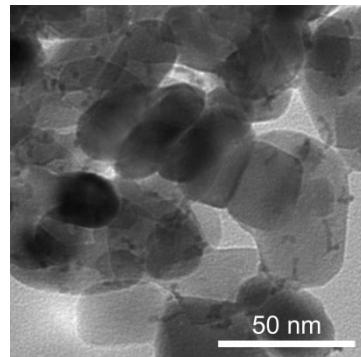


Figure S9. TEM images of Ru NWs/TiO₂ nanostructures after stability test.

Table S1. The table of ICP-AES data of Ru NWs

Ru Catalyst	Concentration(Ru)
Ru NWs/TiO ₂	8.31 μg/mL
Ru NWs(3h)/TiO ₂	6.77 μg/mL
Ru NPs/TiO ₂	6.24 μg/mL
Ru-3nm/TiO ₂ nanostructures	7.21 μg/mL

Table S2. The table of catalysts that are previously reported.

Catalyst	Metal loadings(wt%)	T ₁₀₀	ref.
Ru/MgO		330 °C	1
Ru NWs/TiO ₂	1.2 wt%	150 °C	This work
Ru/Al@γ-Al ₂ O ₃	0.75 wt%	160 °C	2
Ru _(1.5) CeO ₂	1.5 wt%	~160 °C	3
Ru/Al@γ-Al ₂ O ₃		174 °C	4
Cu _{0.2} Ru _{0.8} NPs		~130 °C	5
5.0Ru/CeO ₂ -o	5 wt%	~200 °C	6
Ru _{0.5} Cu _{0.5} ·NPs/Al ₂ O ₃	1 wt%	~150 °C	7
Ru-Loaded·12CaO·7Al ₂ O ₃ 2 wt%		~140 °C	8
m-5RuO ₂ ·10CuO/CeO ₂		95 °C	9

References

- [1] B.B. Sarma, P.N. Plessow, G. Agostini, P. Concepcion, N. Pfander, L.Q. Kang, F.R. Wang, F. Studt, G. Prieto, Metal-specific reactivity in single-atom catalysts: CO oxidation on 4d and 5d transition metals atomically dispersed on MgO, *J. Am. Chem. Soc.*, 2020, 142, 14890–14902.
- [2] I.J. Rah, T.W. Kim, J. Kim, D. Lee, E.D. Park, Selective CO oxidation in the hydrogen stream over Ru/Al@Al₂O₃ catalysts, *Catal. Today*, 2020, 352, 148–156.
- [3] E. Gonzalez-Aa, R. Rangela, A. Solís-Garcia, A.M. Veneziac, T.A. Zepedab, FTIR investigation under reaction conditions during CO oxidation over Ru(x)-CeO₂ catalysts, *Mol. Catal.*, 2020, 493, 111086.
- [4] I.J. Rah, T.W. Kim, J. Kim, D. Lee, E.D. Park, Selective CO oxidation in the hydrogen stream over Ru/Al@Al₂O₃ catalysts, *Catal. Today*, 2020, 352, 148–156.
- [5] B. Huang, H. Kobayashi, T. Yamamoto, T. Toriyama, S. Matsumura, Y. Nishida, K. Sato, K. Nagaoka, M. Haneda, W. Xie, Y. Nanba, M. Koyama, F.L. Wang, S. Kawaguchi, Y.i Kubota, H. Kitagawa, A CO adsorption site change induced by

copper substitution in a Ruthenium catalyst for enhanced CO oxidation activity,
Angew. Chem. Int. Ed., 2019, 58, 2230-2235.

[6] J.H. Li, Z.Q. Liu, R.G. Wang, Support structure and reduction treatment effects on CO oxidation of SiO_2 nanospheres and CeO_2 nanorods supported ruthenium catalysts, J. Colloid Interface Sci., 2018, 531, 204–215.

[7] B. Huang, H. Kobayashi, T. Yamamoto, S. Matsumura, Y. Nishida, K. Sato, K. Nagaoka, S. Kawaguchi, Y. Kubota, H. Kitagawa, Solid-solution alloying of immiscible Ru and Cu with enhanced CO oxidation activity, J. Am. Chem. Soc. 2017, 139, 4643–4646.

[8] M.J. Sharif, M. Kitano, Y. Inoue, Y. Niwa, H. Abe, T. Yokoyama, M. Hara, H. Hosono, Electron donation enhanced CO oxidation over Ru-loaded $12\text{CaO}\cdot7\text{Al}_2\text{O}_3$ Electride Catalyst, J. Phys. Chem. C, 2015, 119, 11725–11731.

[9] X.Z. Cui, Y.X. Wang, L.S. Chen, J.L. Shi, Synergetic catalytic effects in tri-component mesostructured Ru–Cu–Ce oxide nanocomposite in CO oxidation, ChemCatChem, 2014, 6, 2860–2871.