

Supporting information

Orange-peel derived carbon loaded low content ruthenium nanoparticles as ultra-high performance alkaline water HER electrocatalysts

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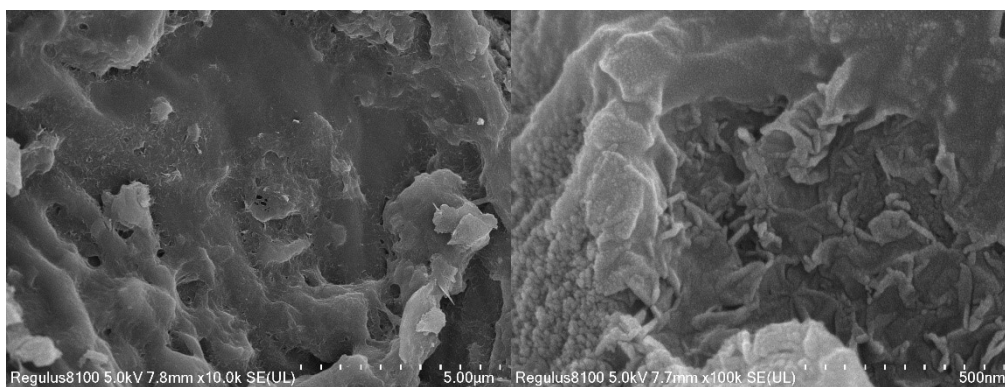


Fig. S1 SEM of OPC

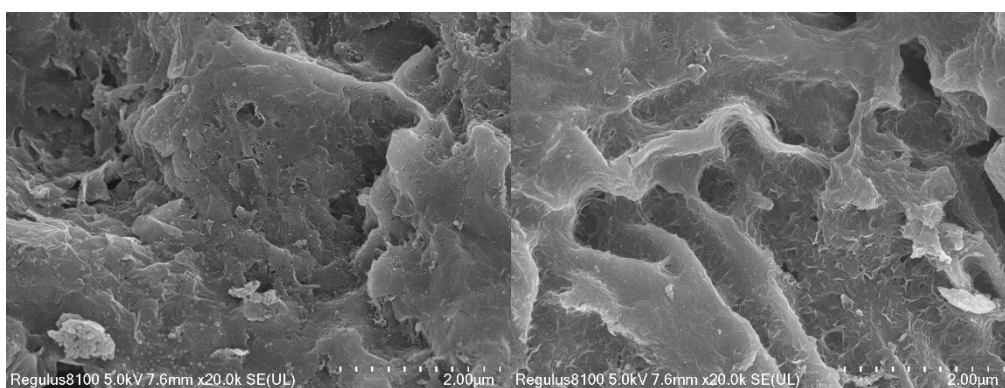
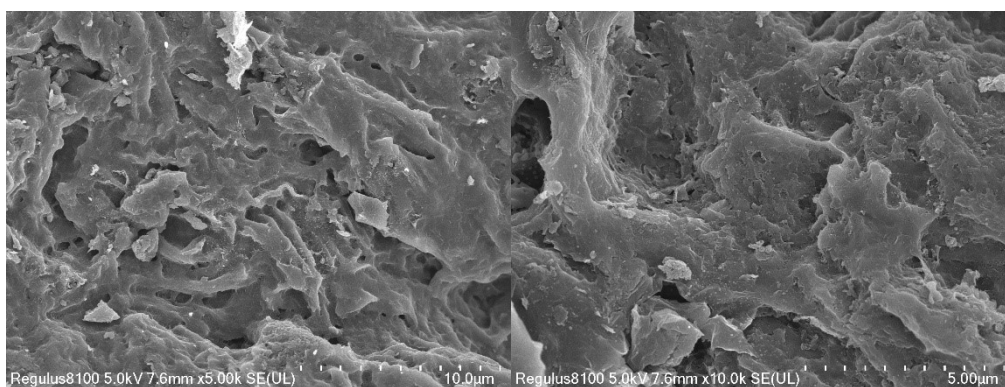


Fig. S2 SEM of Ru/OPC

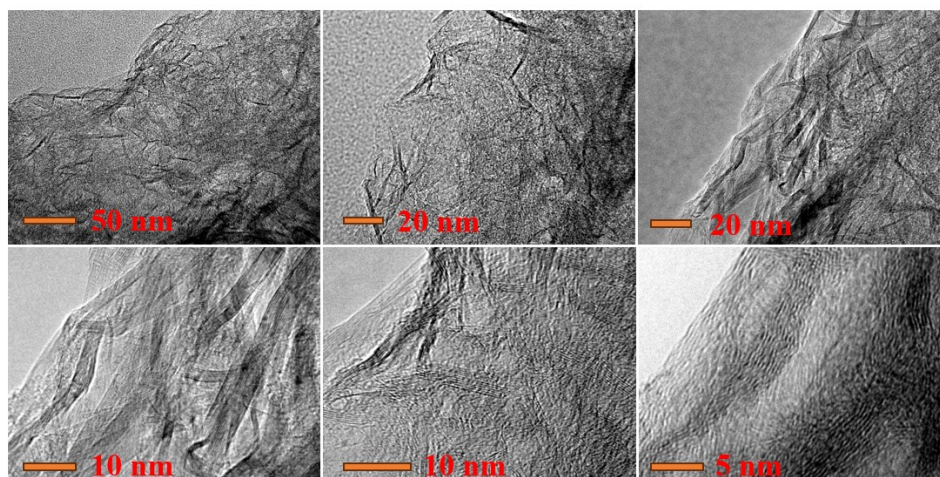


Fig. S3 TEM of OPC

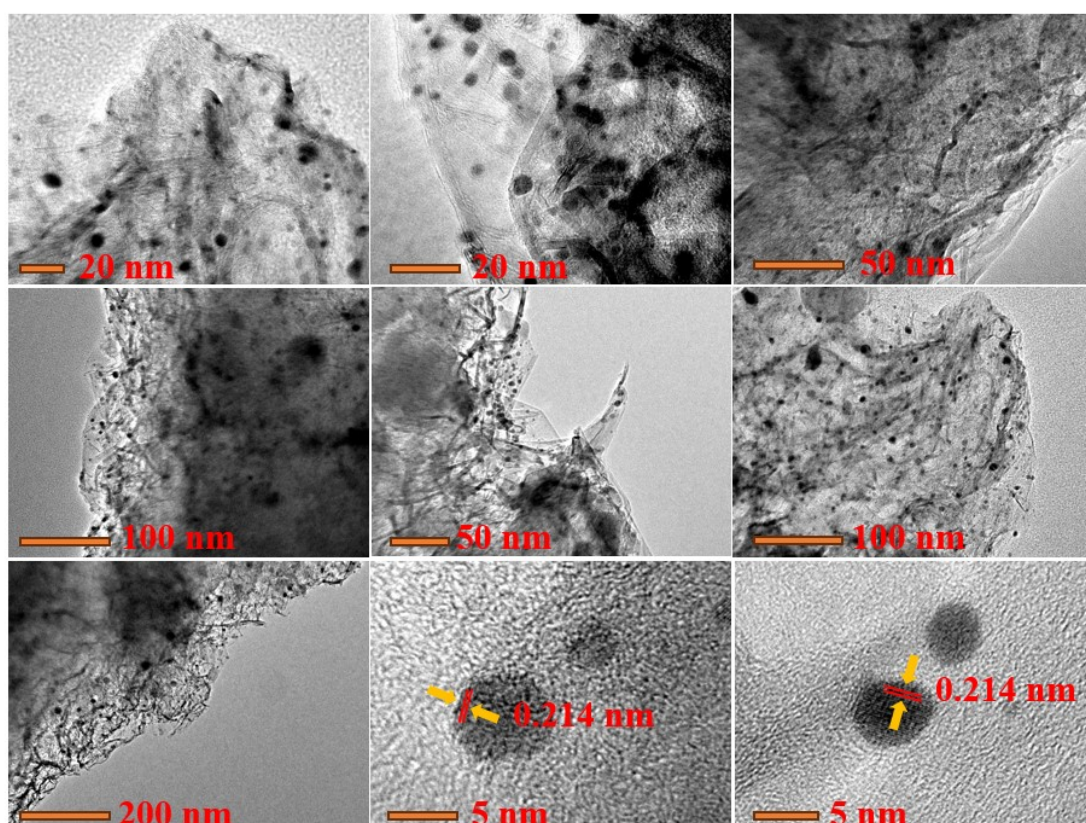


Fig. S4 TEM of Ru/OPC

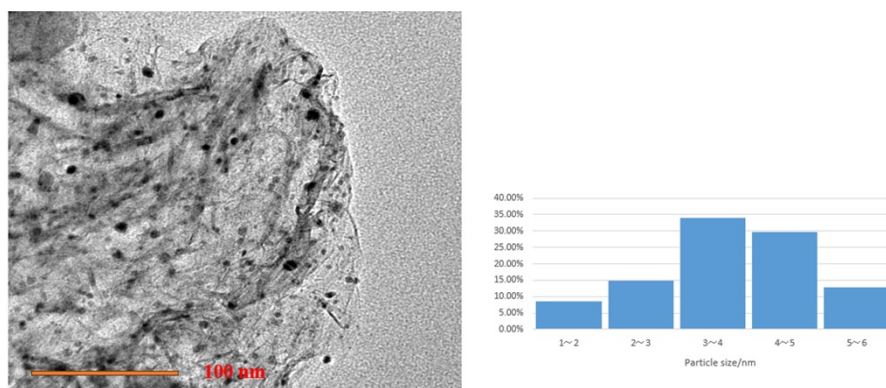


Fig. S5 Particle size distribution of Ru/OPC

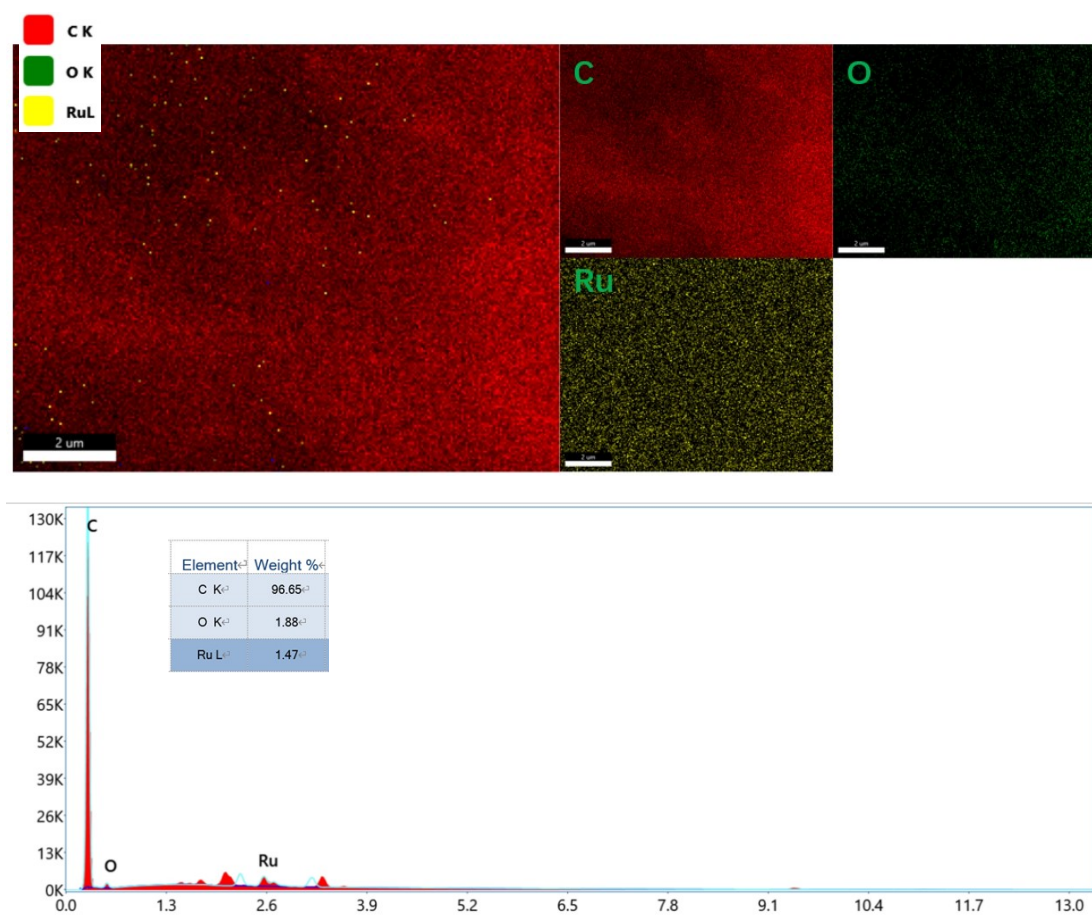


Fig. S6 SEM-EDS mapping of Ru/OPC

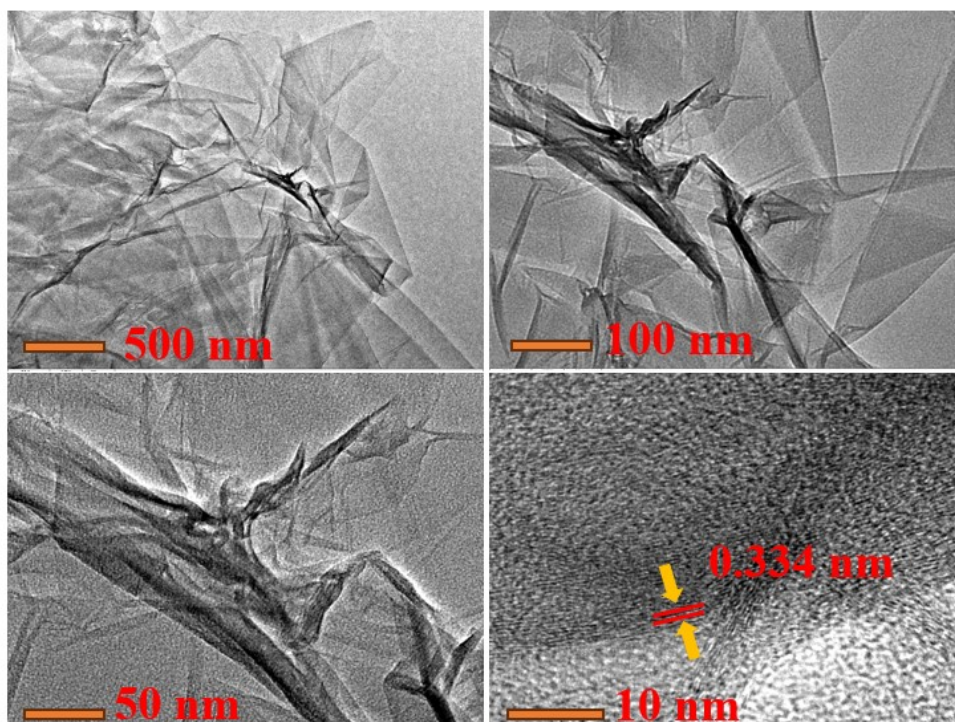


Fig. S7 TEM of rGO

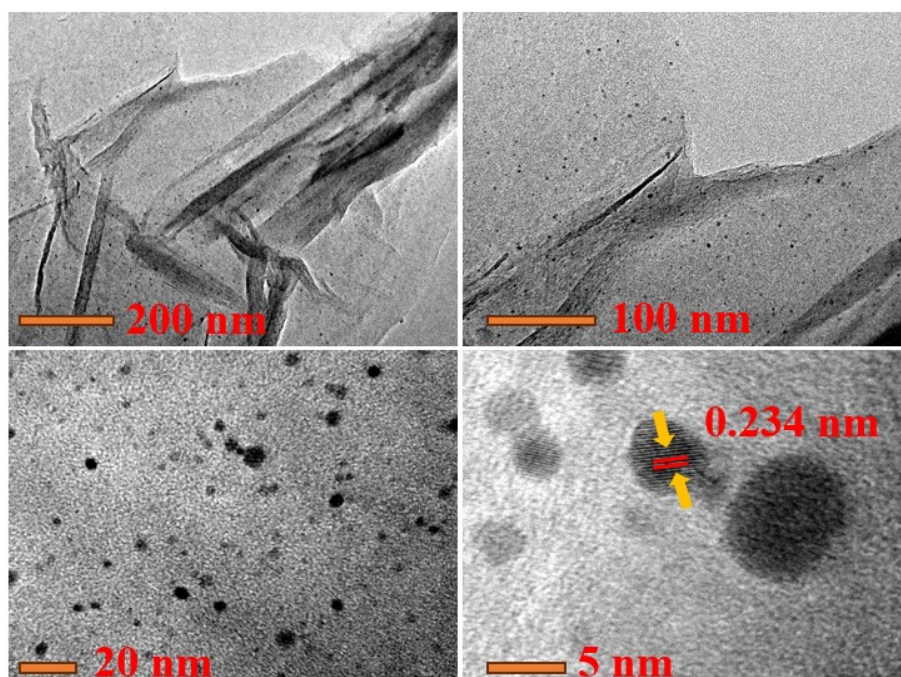


Fig. S8 TEM of Ru/rGO

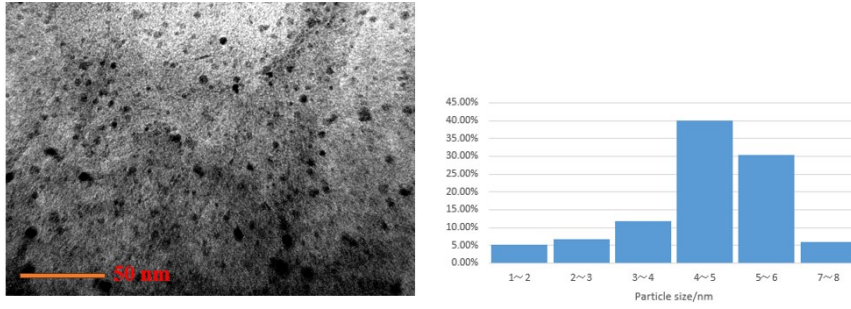


Fig. S9 Particle size distribution of Ru/rGO



Fig. S10 Contact angle of Ru/rGO and Ru/OPC

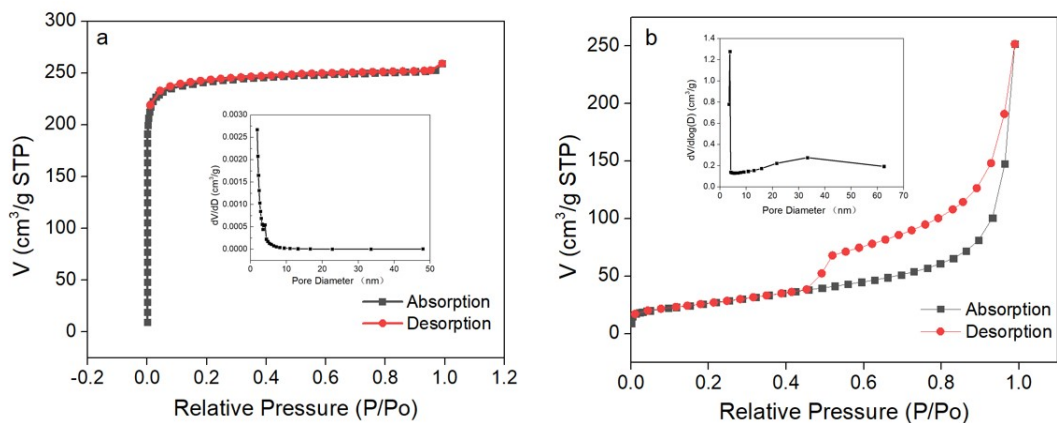


Fig. S11 (a) N₂ adsorption-desorption isotherms and the pore size distribution of Ru/OPC, (b) N₂ adsorption-desorption isotherms and the pore size distribution of Ru/rGO.

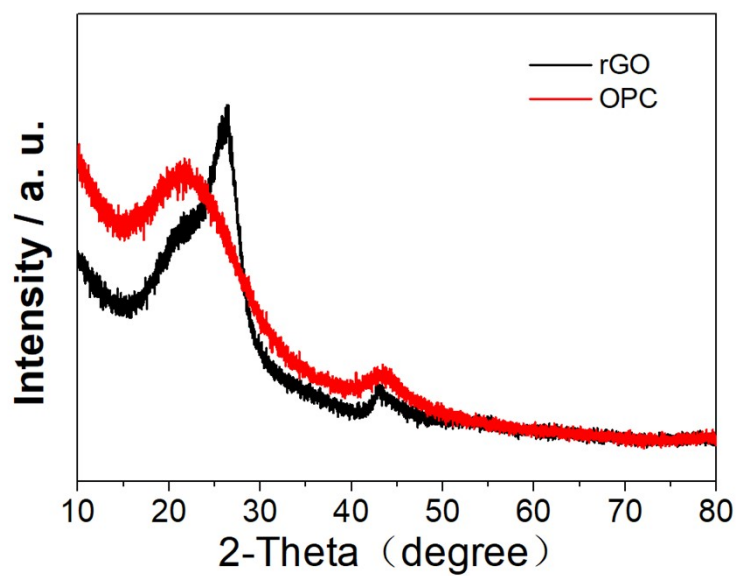


Fig. S12 XRD of rGO and OPC

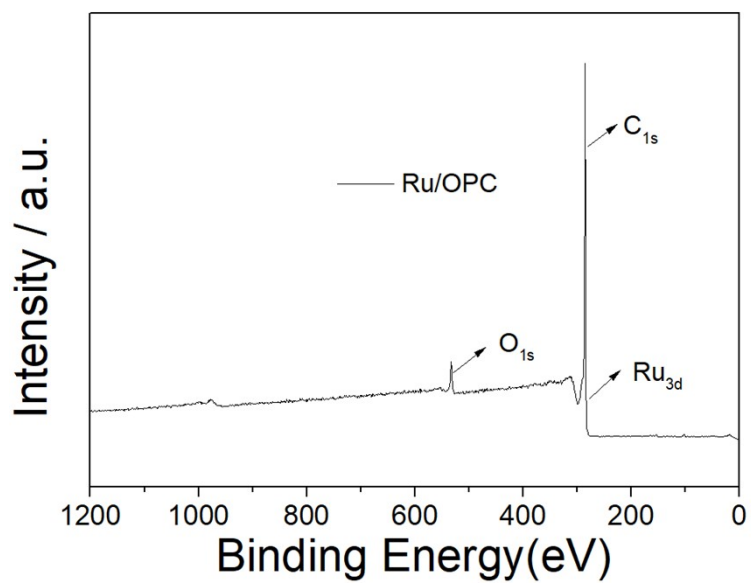


Fig. S13 XPS survey spectra of Ru/OPC

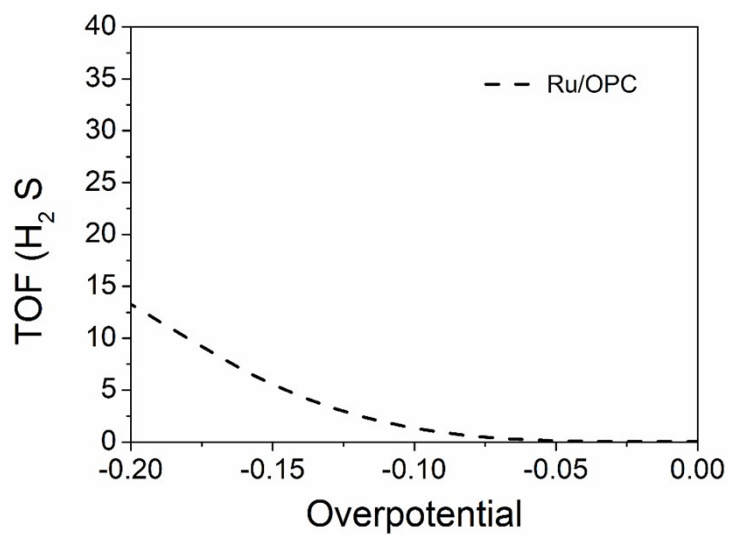


Fig. S14 TOF of Ru/OPC in 0.5 M H₂SO₄

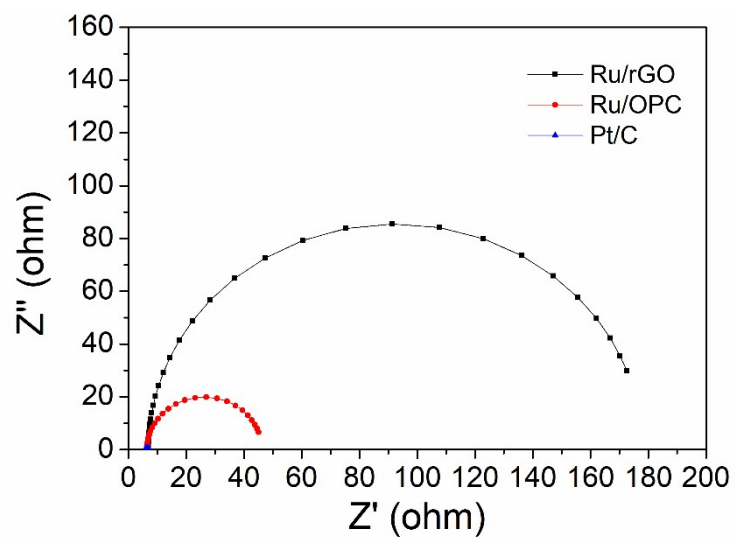


Fig. S15 EIS of Ru/OPC in 0.5 M H₂SO₄

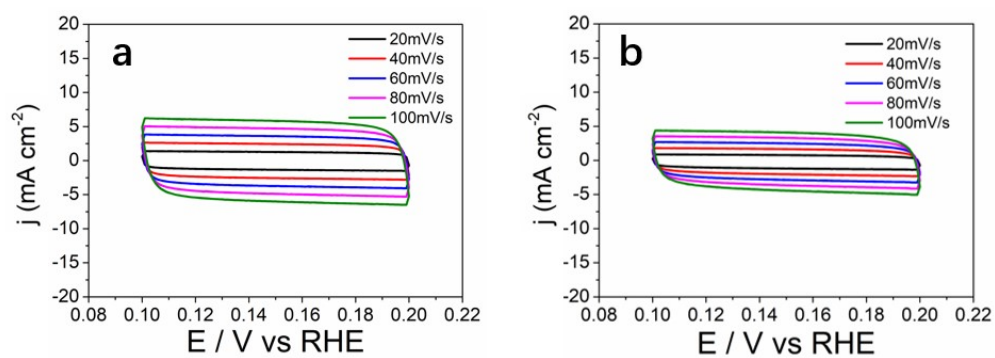


Fig. S16 CV curves of Ru/rGO (a) in 1 M KOH, (b) in 0.5 M H₂SO₄

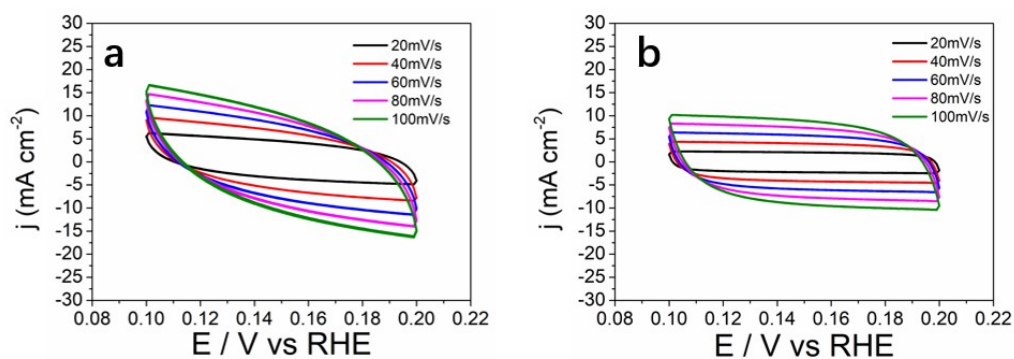


Fig. S17 CV curves of Ru/OPC (a) in 1 M KOH, (b) in 0.5 M H₂SO₄

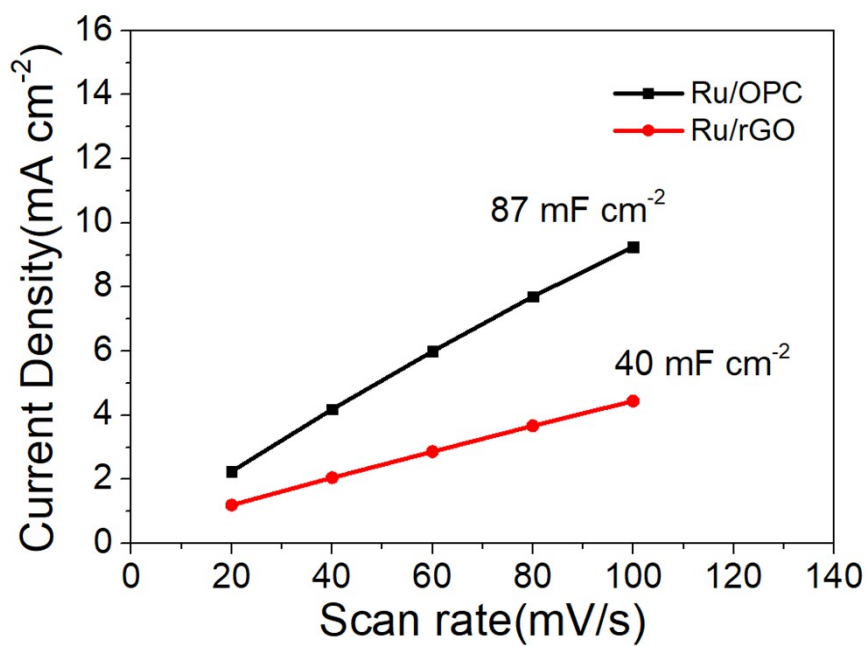


Fig. S18 The linear slope of Ru/rGO and Ru/OPC, equivalent to twice the double-layer capacitance (C_{dl}) in 0.5 M H₂SO₄.

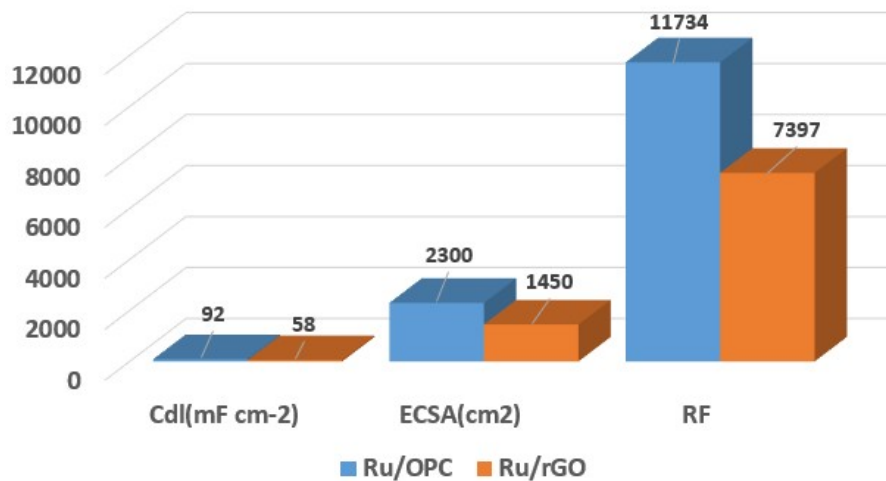


Fig. S19 C_{dl} , ECSA, RF of the Ru/OPC and Ru/rGO in 1 M KOH.

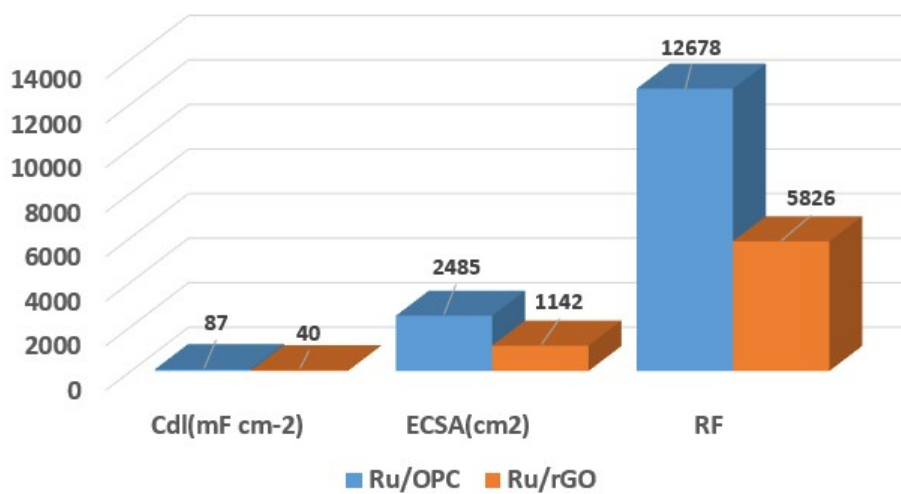


Fig. S20 C_{dl} , ECSA, RF of the Ru/OPC and Ru/rGO in 0.5 M H₂SO₄.

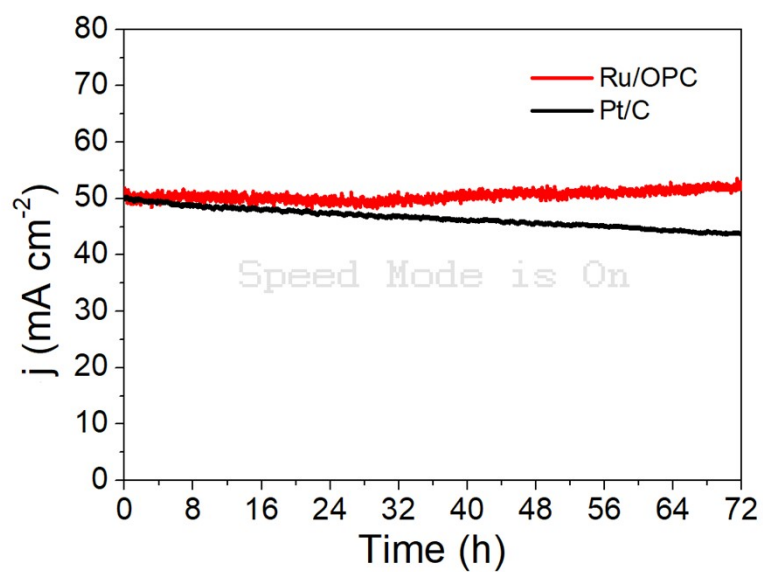


Fig. S21 Long-term i-t response test for Ru/OPC and Pt/C in 0.5 M H₂SO₄.

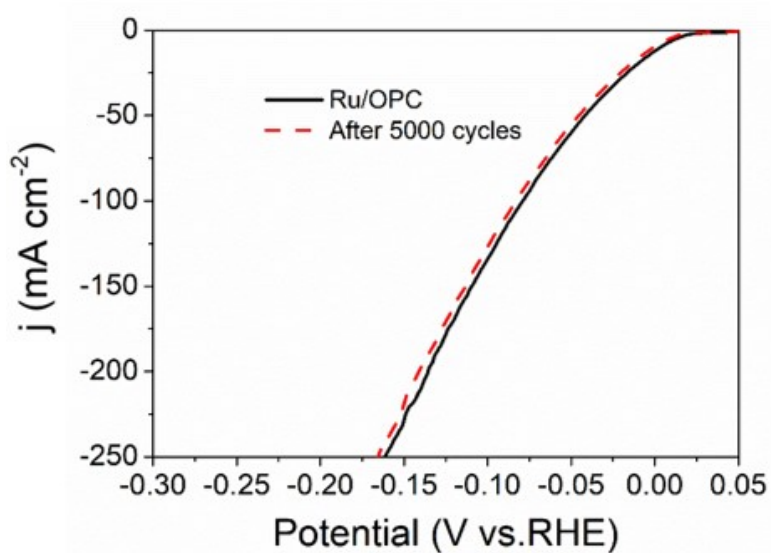


Fig. S22 LSVs of Ru/OPC catalysts before and after 5000 CV cycles in 1 M KOH

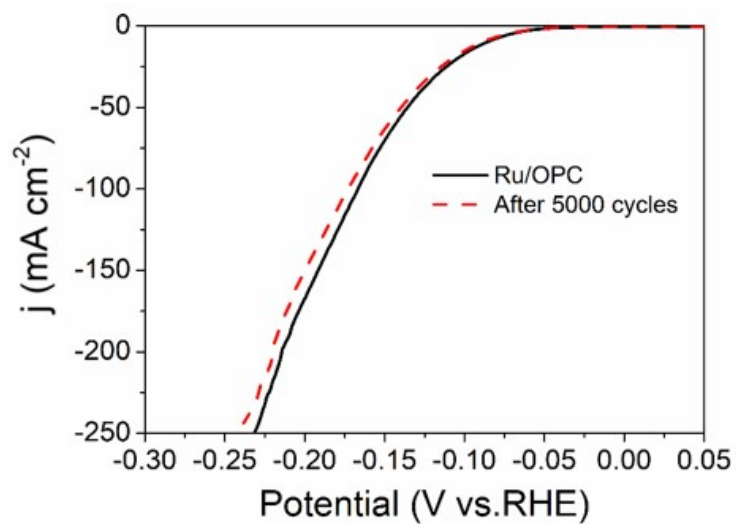


Fig. S23 LSVs of Ru/OPC catalysts before and after 5000 CV cycles in 0.5 M H₂SO₄

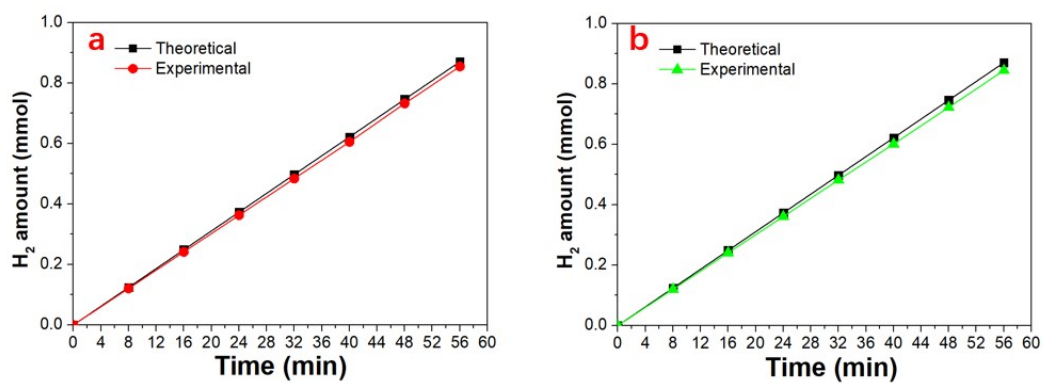


Fig. S24 Faradaic efficiency of Ru/OPC in 1 M KOH (a) and 0.5 M H₂SO₄ (b).

Table S1. Summary of HER catalytic activities of Ru/OPC and some other catalysts reported in recent literatures (1 M KOH).

Catalysts	Overpotential	Tafel Slope (mV dec ⁻¹)	Ref.
Ru/OPC	3 mV at 10 mA cm ⁻²	49	In this work
Ru-CoP/NC	22 mV at 10 mA cm ⁻²	50	ACS Appl. Mater. Interfaces, 2021, 13, 56035–56044.
Ru/C	39 mV at 10 mA cm ⁻²	/	ACS Appl. Energy Mater., 2021, 4, 4284–4289.
CoRu-O/A@HNC-2	85 mV at 10 mA cm ⁻²	72.5	ACS Appl. Mater. Interfaces, 2020, 12, 51437–51447.
Ru@NC	39 mV at 10 mA cm ⁻²	37.9	ACS Sustainable Chem. Eng., 2022, 10, 15530–15537.
ld-Ru@a-Co/Ti	33.5 mV at 10 mA cm ⁻²	39.6	Chem. Commun., 2022, 58, 13588–13591.
Ni2P–Ru/NF	40 mV at 10 mA cm ⁻²	33.9	Sustainable Energy Fuels, 2023, 7, 2830–2840.
Ru/Mo2C@NC	13 mV at 10 mA cm ⁻²	33.2	J. Mater. Chem. A, 2021, 9, 20518–20529.
Ru/PEI-XC	13 mV at 10 mA cm ⁻²	79.3	J. Mater. Chem. A, 2021, 9, 22934–22942.
MoRu/C	27.1 mV at 5 mA cm ⁻²	51	Chem. Commun., 2020, 56, 14475–14478.
D/NFF-Ru-Zn	90 mV at 100 mA cm ⁻²	41	J. Mater. Chem. A, 2022, 10, 20453–20463.
CF@Ru-CoCH NWs	121 mV at 100 mA cm ⁻²	65	Electrochim. Acta, 2020, 331, 135367
Ru/TiOxNy NBs	16 mV at 10 mA cm ⁻²	42	J. Mater. Chem. A, 2022, 10, 11205–11212.
RuCr@C	19 mV at 10 mA cm ⁻²	24	Adv. Funct. Mater., 2021, 32, 2108991.
Ru MNSs	24 mV at 10 mA cm ⁻²	33	Angew. Chem. Int.

			Ed. Engl., 2022, e202116867.
P-Ru-CoNi-LDH	29 mV at 10 mA cm ⁻²	69	Small, 2022, 18, e2104323.
CC@WS2/Ru-450	32.1 mV at 10 mA cm ⁻²	53.2	Adv. Funct. Mater., 2022, 2109439.
Ru-HMT-MP-7	33 mV at 10 mA cm ⁻²	26.4	Small, 2022, e2105168.
Ni5P4-Ru	155 mV at 10 mA cm ⁻²	92	Adv. Mater., 2020, 32, e1906972.
Ru-NiCo2S	32 mV at 10 mA cm ⁻²	41.3	Adv. Funct. Mater., 2021, 2109731.
RuRh-Co	32 mV at 10 mA cm ⁻²	31	Nano Energy, 2021, 90, 106579.