Electronic Supplementary Information for

Hollow Ru/RuO_2 nanospheres with nanoparticulate shells for high performance electrocatalytic oxygen evolution reactions

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Fig. S1 Low magnification SEM images of H-MOP-Ru and HN-Ru/RuO_2.

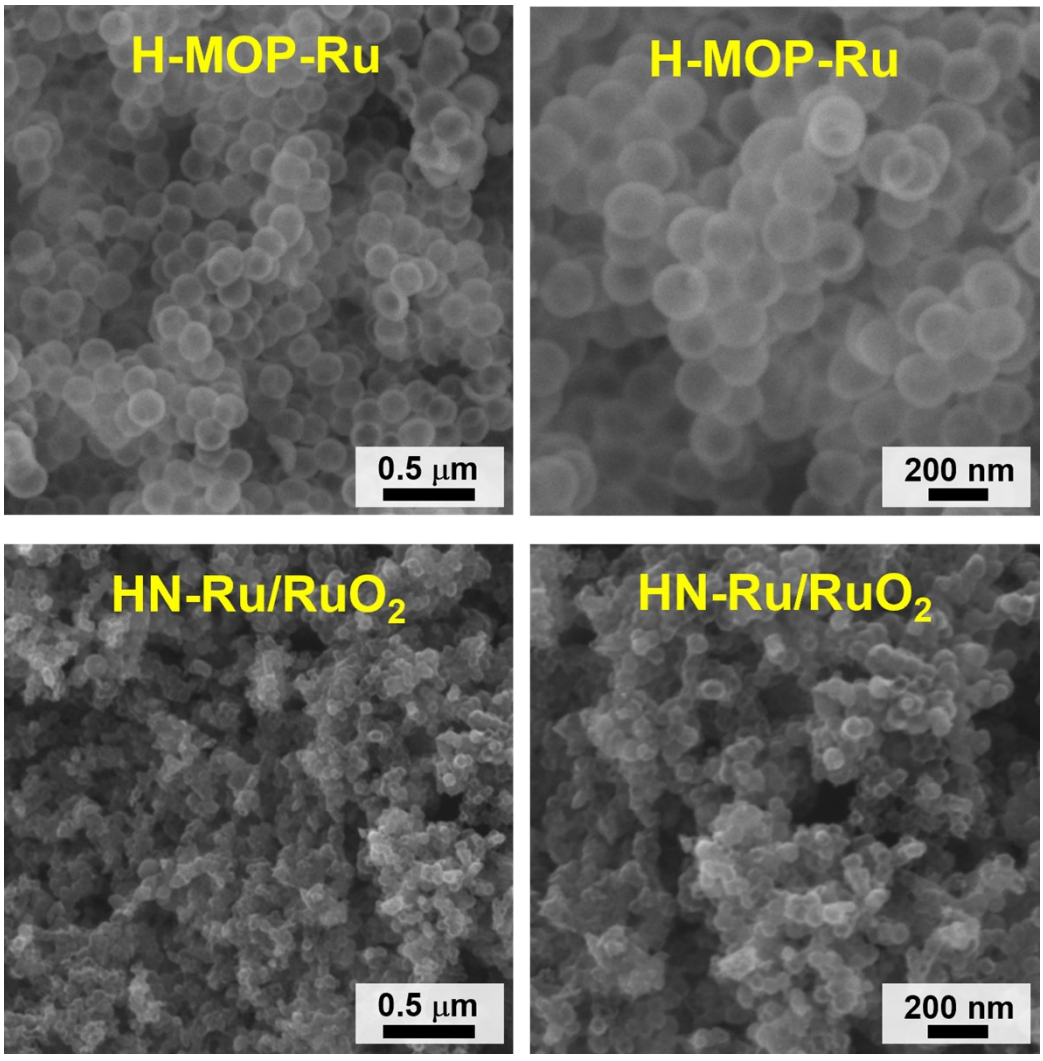


Fig. S2 Powder XRD patterns of H-MOP-CatP, H-MOP-Cat, and H-MOP-Ru.

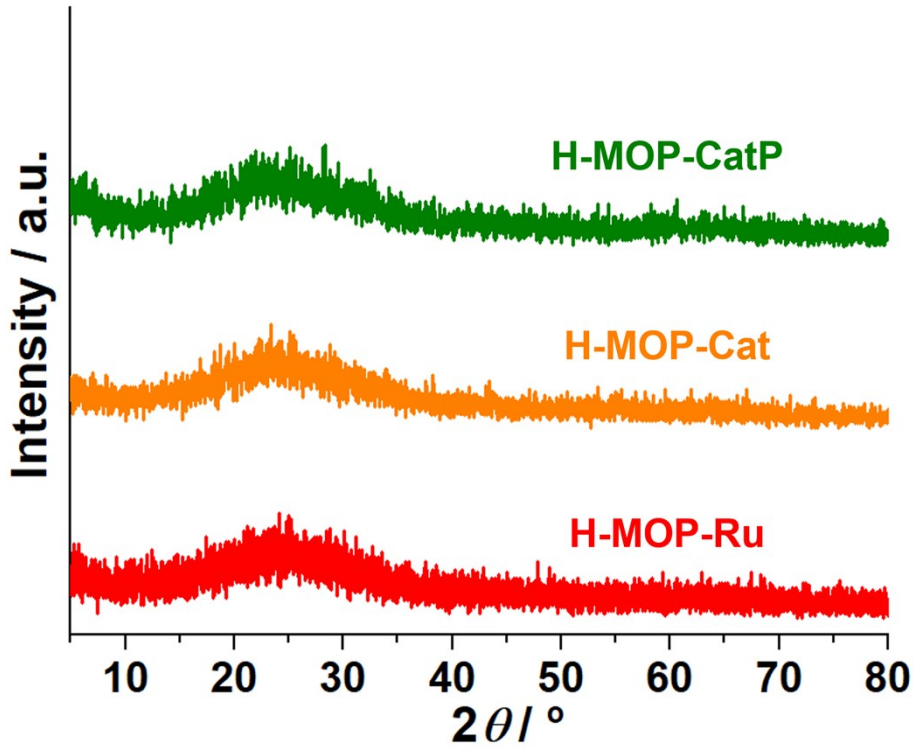


Fig. S3 TGA curves of H-MOP-CatP, H-MOP-Cat, and H-MOP-Ru.

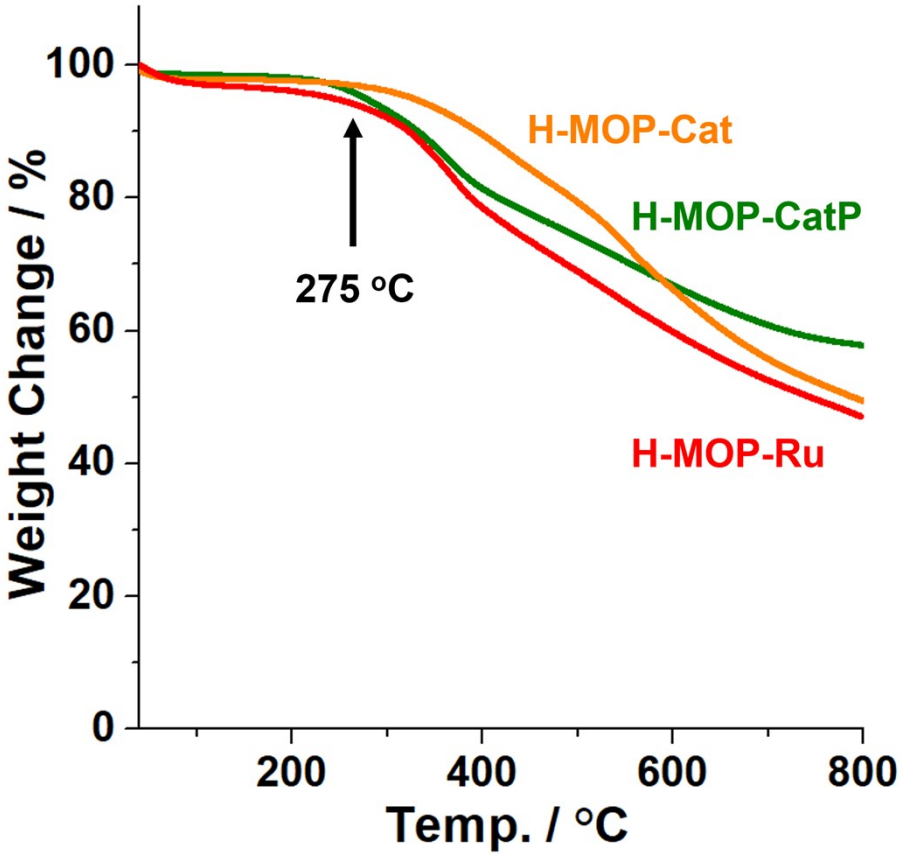
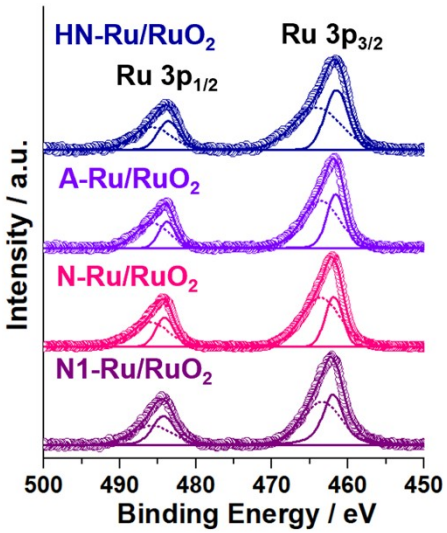
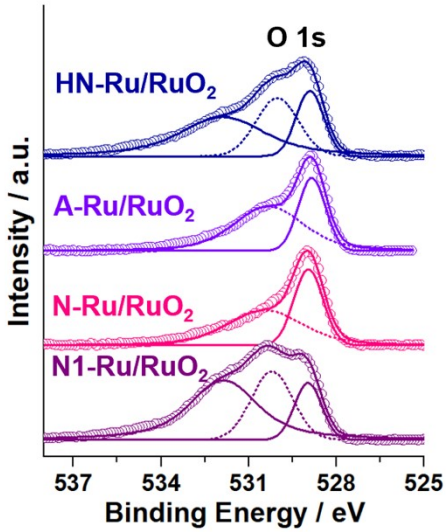


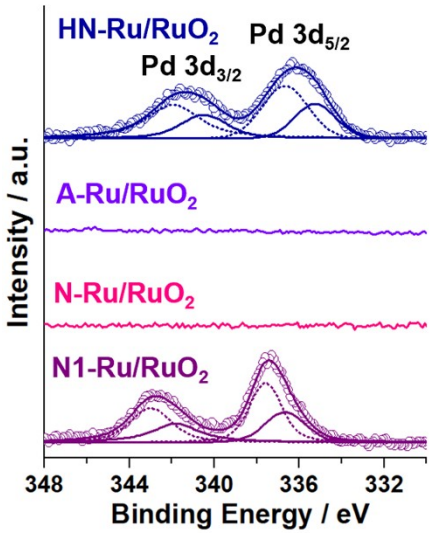
Fig. S4 XPS spectra of Ru 3p orbitals, O 1s orbitals, and Pd 3d orbitals of HN-Ru/RuO_2, A-Ru/RuO_2, N-Ru/RuO_2, and N1-Ru/RuO_2.



HN-Ru/RuO_2	Peak	p1	p2	p3	p4
	Position (eV)	461.48	464.08	483.58	485.75
	FWHM	3.57	7.39	3.30	5.93
	Area (%)	28.2	41.5	12.4	17.9
	r^2	0.996			
A-Ru/RuO_2	Peak	p1	p2	p3	p4
	Position (eV)	461.60	463.57	483.78	485.72
	FWHM	2.79	5.77	2.56	5.21
	Area (%)	24.6	44.7	10.5	20.2
	r^2	0.997			
N-Ru/RuO_2	Peak	p1	p2	p3	p4
	Position (eV)	461.84	463.58	484.06	486.00
	FWHM	2.72	5.97	2.80	5.78
	Area (%)	20.4	45.2	12.3	22.1
	r^2	0.999			
N1-Ru/RuO_2	Peak	p1	p2	p3	p4
	Position (eV)	461.95	463.41	484.23	485.72
	FWHM	3.23	6.04	3.46	6.21
	Area (%)	29.1	37.7	16.1	17.1
	r^2	0.997			



HN-Ru/RuO_2	Peak	p1	p2	p3
	Position (eV)	528.91	530.02	531.90
	FWHM	1.11	1.71	3.47
	Area (%)	21.7	29.8	48.5
	r^2	0.997		
A-Ru/RuO_2	Peak	p1	p2	-
	Position (eV)	528.84	530.32	-
	FWHM	1.10	2.82	-
	Area (%)	36.5	63.5	-
	r^2	0.993		
N-Ru/RuO_2	Peak	p1	p2	-
	Position (eV)	528.96	530.44	-
	FWHM	1.17	3.06	-
	Area (%)	42.8	57.2	-
	r^2	0.991		
N1-Ru/RuO_2	Peak	p1	p2	p3
	Position (eV)	528.97	530.20	531.86
	FWHM	1.09	1.67	2.77
	Area (%)	16.5	30.1	53.4
	r^2	0.997		



HN-Ru/RuO_2	Peak	p1	p2	p3	p4
	Position (eV)	335.24	336.66	340.48	341.94
	FWHM	2.28	2.55	2.58	2.99
	Area (%)	20.2	34.5	17.8	27.5
	r^2	0.992			
N1-Ru/RuO_2	Peak	p1	p2	p3	p4
	Position (eV)	336.66	337.58	341.80	342.99
	FWHM	2.23	1.81	2.63	2.30
	Area (%)	19.2	33.3	18.0	29.5
	r^2	0.991			

Fig. S5 Scan rate-dependent cyclic voltammograms of HN-Ru/RuO_2, A-Ru/RuO_2, N-Ru/RuO_2, and N1-Ru/RuO_2.

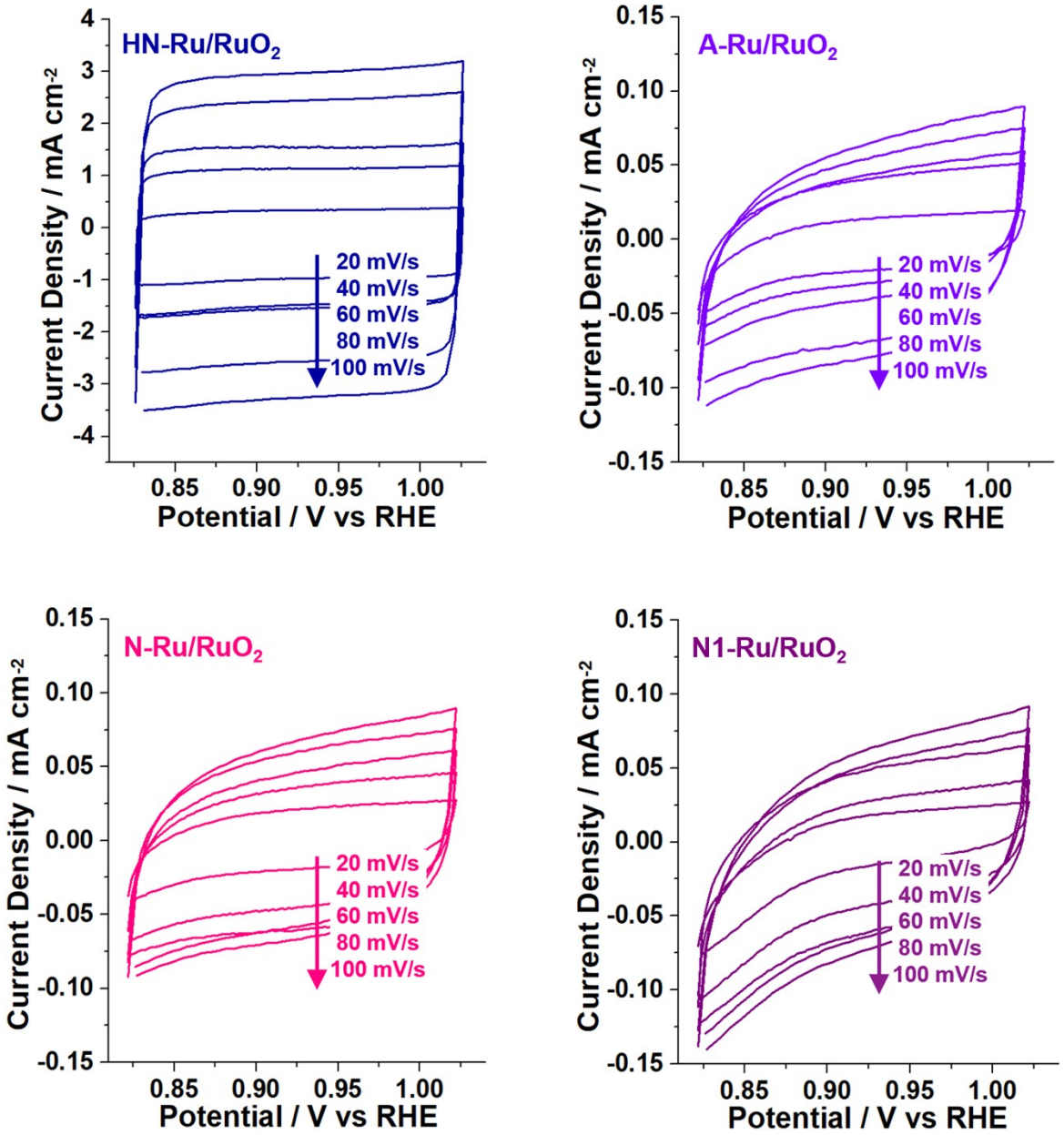
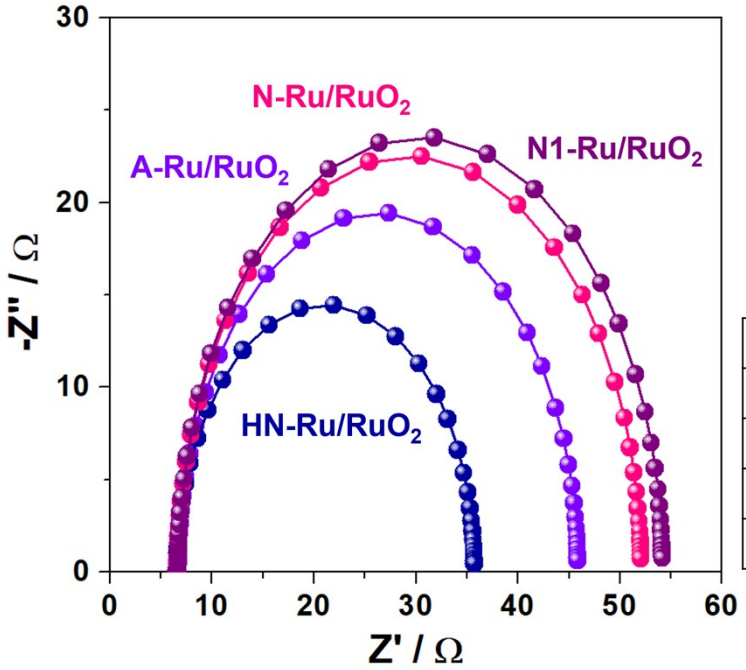
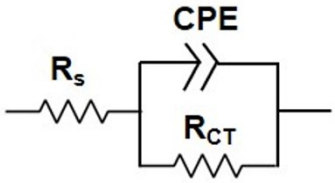


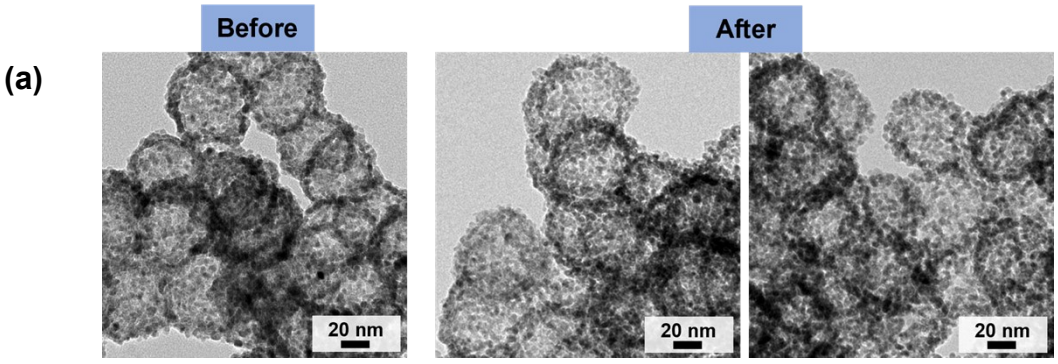
Fig. S6 Nyquist plots of HN-Ru/RuO_2, A-Ru/RuO_2, N-Ru/RuO_2, and N1-Ru/RuO_2 (Electrochemical impedance spectroscopy was conducted at the onset potential of 1.4 V vs RHE within a frequency range of 0.1~100 kHz with a signal amplitude of 10 mV).

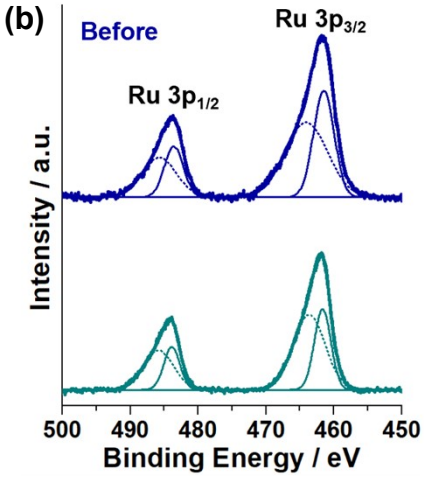




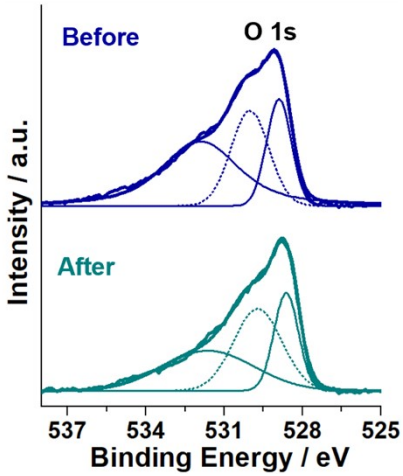
Materials	R_s (Ω)	R_{ct} (Ω)
HN-Ru/RuO_2	6.5	29.2
A-Ru/RuO_2	6.5	39.3
N-Ru/RuO_2	6.6	45.5
N1-Ru/RuO_2	6.6	47.5

Fig. S7 (a) TEM and (b) XPS analysis of HN-Ru/RuO_2 retrieved after durability tests.





Before HN-Ru/RuO_2	Peak	p1	p2	p3	p4
	Position (eV)	461.48	464.08	483.58	485.75
	FWHM	3.57	7.39	3.30	5.93
	Area (%)	28.2	41.5	12.4	17.9
	r^2	0.996			
After HN-Ru/RuO_2	Peak	p1	p2	p3	p4
	Position (eV)	461.66	463.66	483.87	485.84
	FWHM	2.87	5.57	2.78	5.23
	Area (%)	23.7	42.9	12.2	21.1
	r^2	0.997			



Before HN-Ru/RuO_2	Peak	p1	p2	p3
	Position (eV)	528.91	530.02	531.90
	FWHM	1.11	1.71	3.47
	Area (%)	21.7	29.8	48.5
	r^2	0.997		
After HN-Ru/RuO_2	Peak	p1	p2	p3
	Position (eV)	528.62	529.71	531.61
	FWHM	1.10	2.18	4.15
	Area (%)	23.8	39.4	36.7
	r^2	0.997		

Fig. S8 HER performance of HN-Ru/RuO_2 and N-Ru/RuO_2 (Ar-saturated 1.0 M KOH, working electrode: graphite, reference electrode: Ag/AgCl): (a) HER polarization curves and overpotentials at 10 mA/cm^2 (scan rate: 10 mV/s) and (b) Tafel plots.

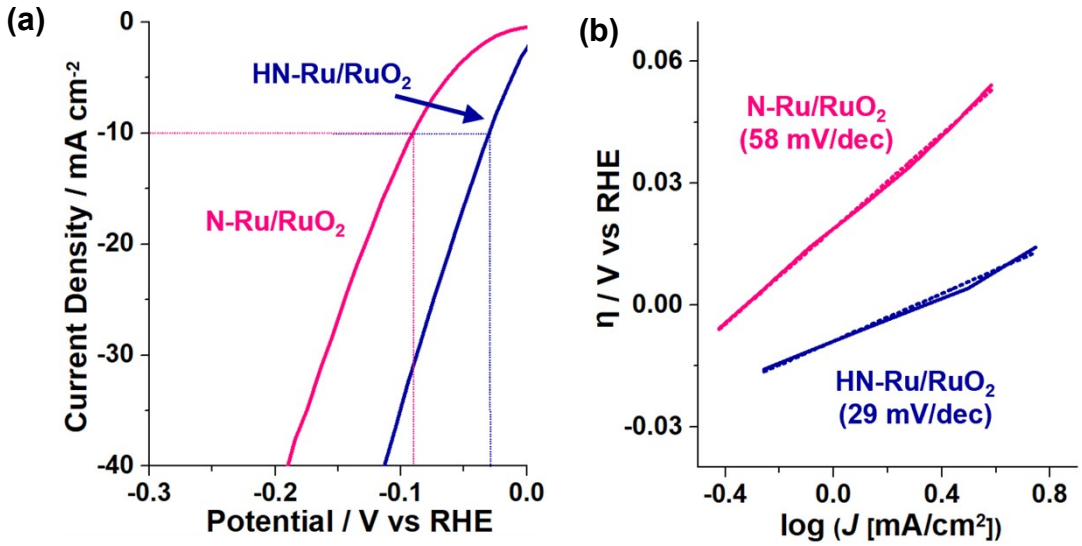


Table S1 Physical parameters of H-MOP-CatP, H-MOP-Cat, H-MOP-Ru, HN-Ru/RuO_2, A-Ru/RuO_2, N-Ru/RuO_2, and N1-Ru/RuO_2.

Materials	SA_{BET} [a] (m^2/g)	V_{mic} [b] (cm^3/g)	V_t [c] (cm^3/g)
H-MOP-CatP	339	0.088	0.30
H-MOP-Cat	569	0.14	0.38
H-MOP-Ru	361	0.087	0.24
HN-Ru/RuO_2	80	-	0.18
A-Ru/RuO_2	10	-	0.019
N-Ru/RuO_2	6	-	0.010
N1-Ru/RuO_2	11	-	0.031

[a] Surface area obtained by a BET plot. [b] Micropore volume obtained by a t-plot. [c] Total pore volume.

Table S2 Electrocatalytic performance of RuO_2-based materials for OER in alkaline electrolytes.

Entry	Materials	Strategy	Overpotential @10 mA/cm^2 (mV)	Tafel slope (mV/dec)	Electrolyte	Year	Ref
1	RuO_2/NCNTs	Carbon composites	350	65	0.1 M KOH	2016	1
2	RuO_2/C nanoparticles	Carbon composites	-	69	0.1 M KOH	2017	2
3	RuO_2/N-C	Carbon composites	280	56	1 M KOH	2018	3
4	Ru/RuO_2 nanorods	Nanoengineering	320	86	0.1 M KOH	2019	4
5	RuO_2/C	Carbon composites	300	116	0.1 M KOH	2019	5
6	Ru/RuO_2/CNT	Carbon composites	209	64	1 M KOH	2020	6
7	RuO_2/CeO_2 nanoparticles	Metal oxide composites	350	74	1 M KOH	2020	7
8	RuO_2/F-doped graphene	Carbon composites	239	56	1 M KOH	2020	8
9	Ru/RuO_2/N-rGO	Carbon composites	255	89.4	1 M KOH	2020	9
10	CoOx-RuO_2/NF	Carbon composites	420	69.6	1 M KOH	2020	10
11	RuO_2/Co_3O_4	Metal oxide composites	302	74.37	0.1 M KOH	2020	11
12	RuO_2 nanoplates	Nanoengineering	400	82.5	1 M KOH	2022	12
13	HN-Ru/RuO_2	Nanoengineering	295	46	1 M KOH	This work	

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