Electronic Supplementary Information

Hetero-structured Ru-Mo_2C nanoparticles loaded on N, P co-doped carbon for pH universal hydrogen evolution reaction

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1. Materials characterization

The microstructure of the catalysts was observed by scanning electron microscope (SEM, Nova Nano SEM 450) and transmission electron microscopy (TEM, JEM-2100F). The catalyst's phase and composition were measured by X-ray diffraction (XRD, Lab XRD-7000s) and X-ray photoelectron spectroscopy (XPS, ESCALAB250Xi). The gas adsorption-desorption curves were measured on a surface area analyzer (Micromeritics 3020 instrument).

2. Electrochemical Measurements

Electrochemical measurements were performed in 1.0 M KOH using the standard three-electrode system. Graphite rod, Ag/AgCl (KCl saturated) electrode, and electrocatalyst modified glassy carbon electrode (polished using α-Al_2O_3) are used as the counter electrode, reference electrode, and working electrode, respectively. The catalyst ink is prepared by dispersing 5 mg catalyst into a mixture of 480 μL H_2O, 480 μL ethanol and 40 μL Nafion. The 16 μL catalyst ink was dipped onto the glass carbon and dried naturally under room temperature. The loading of catalysts is 0.4 mg m^{-2}, and the Ru content for Ru-Mo_2C@NPC is 0.023 mg cm^{-2}. The linear sweep voltammetry (LSV) test is performed at a scan rate of 5 mVs^{-1} with 85% IR compensation. Electrochemical impedance spectroscopy (EIS) was measured at a frequency of 0.01-10^5 Hz at 0.5 V.

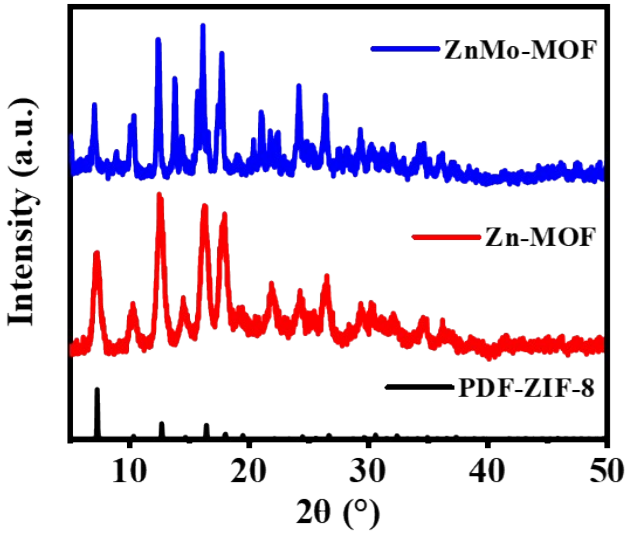

Figure S1. XRD patterns of Zn-MOF and ZnMo-MOF.

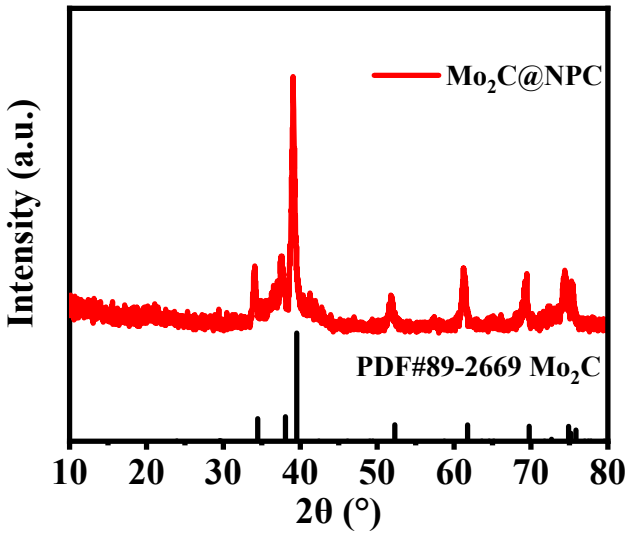

Figure S2. XRD pattern of Mo_2C@NPC.

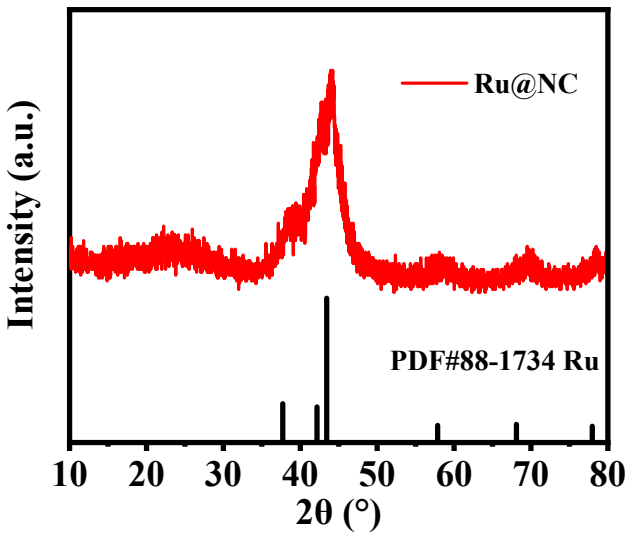

Figure S3. XRD pattern of Ru@NC.

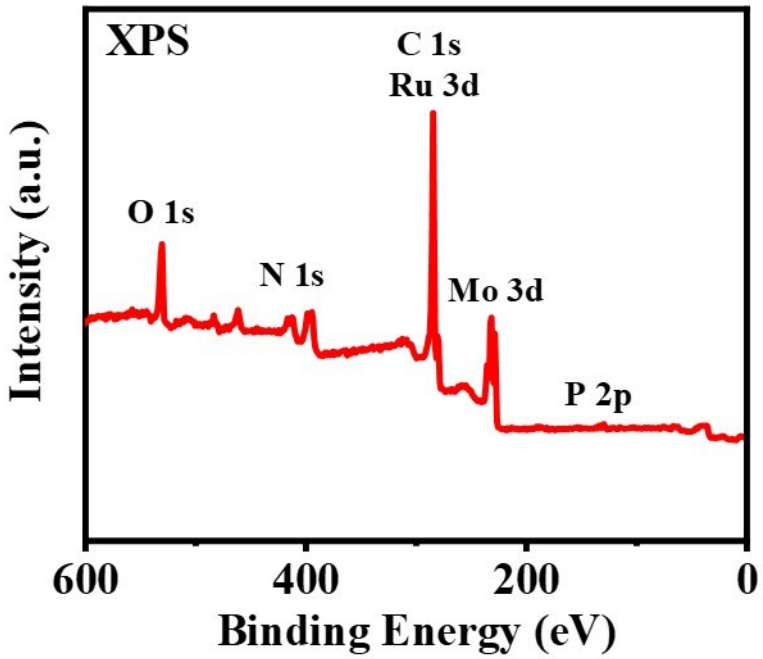

Figure S4. XPS survey spectra of Ru-Mo_2C@NPC.

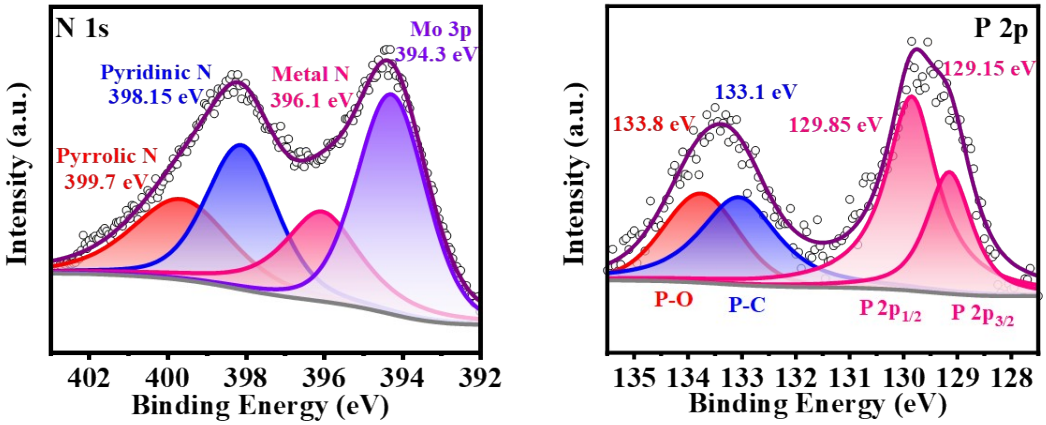

Figure S5. N 1s and P 2p spectra of Ru-Mo_2C@NPC.

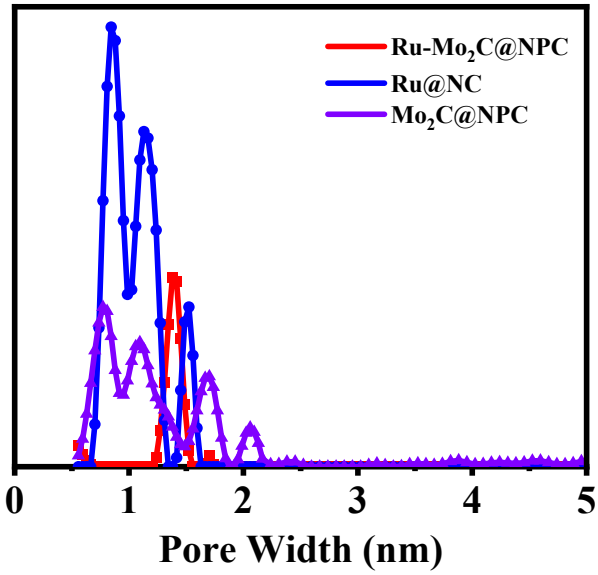

Figure S6. Pore size distribution of the catalysts.

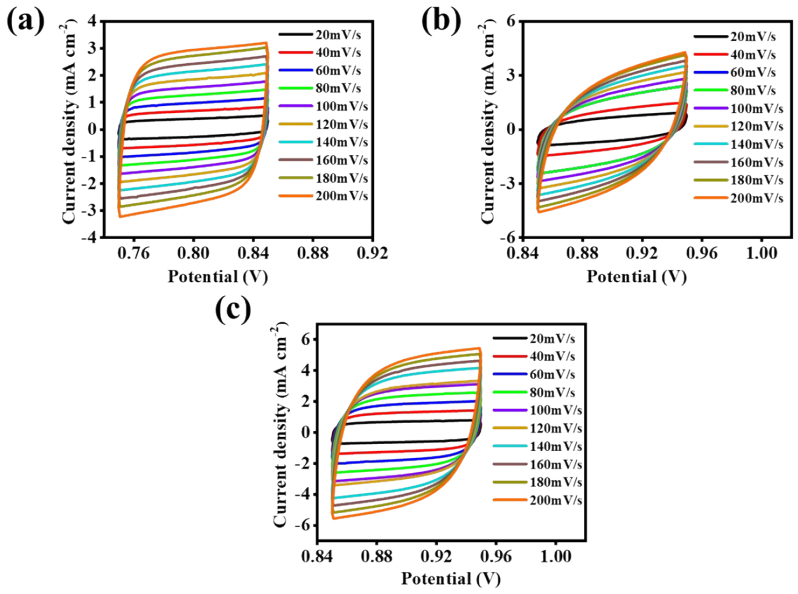

Figure S7. The CV curves of Ru-Mo_2C@NPC (a), Ru@NC (b) and Mo_2C@NPC in 0.5 M H_2SO_4.

Table S1 Comparison of HER properties of Ru-Mo_2C@NPC and other molybdenum carbide-based catalysts

Materials	Electrolyte	η_{10} (HER, mV)	Ref.
Ru-Mo_2C@NPC	1 M KOH	64	This work
	0.5 H_2SO_4	62	
	1 M PBS	170	
Ru/Mo_2C	1 M KOH	35	[1]
	0.5 H_2SO_4	44	
	1 M PBS	196	
Ru-Mo_2C@CSC	1 M KOH	40	[2]
Mo_2C/CN	1 M KOH	34	[3]
Ru@2H-MoS_2	1 M KOH	51	[4]
	0.5 H_2SO_4	168	
	1 M PBS	137	
Ru-CoP	1 M KOH	47	[5]
	0.5 H_2SO_4	80	
	1 M PBS	107	
HMCs@Ru	1 M KOH	64	[6]
	0.5 H_2SO_4	2.8	
	0.5 M PBS	78	

Reference

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