

Supporting Information

Modulating Fe spin state in FeNC catalysts by Ru nanoparticles to facilitate oxygen reduction reaction

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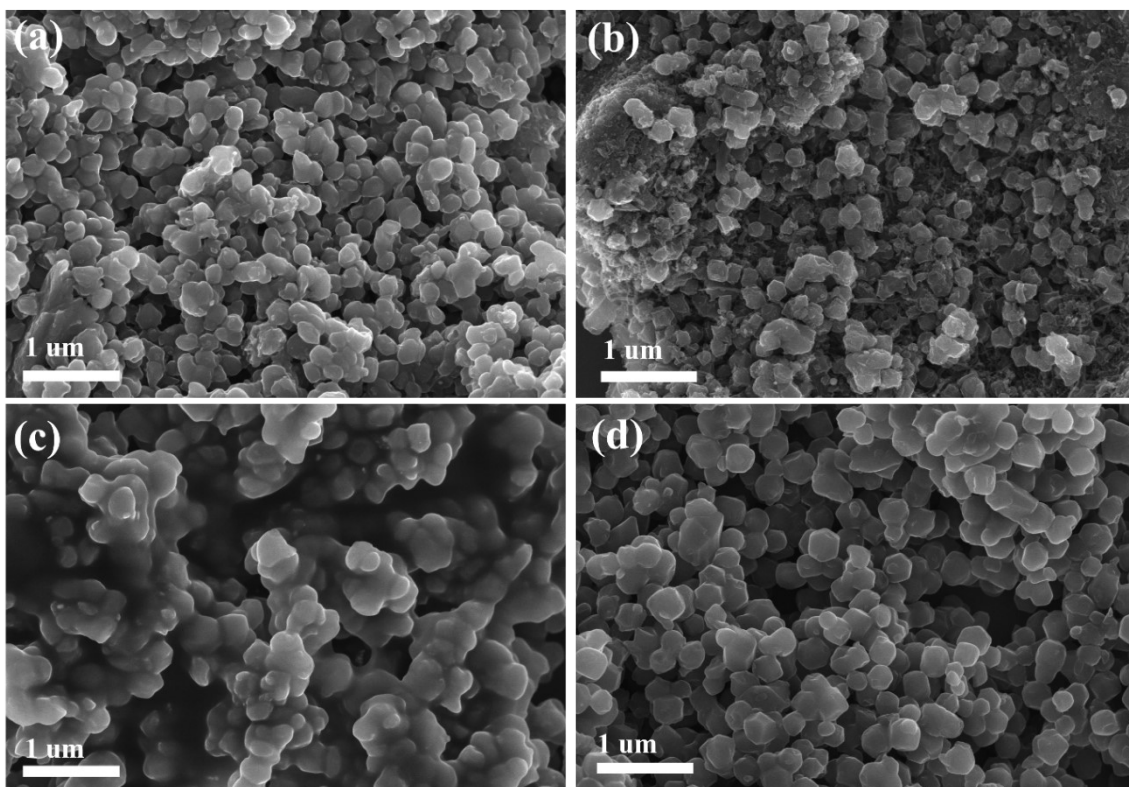


Figure S1. SEM images of (a) Ru_{NP}@FeNC, (b) FeNC, (c) Ru_{NP}@NC, (d) NC.

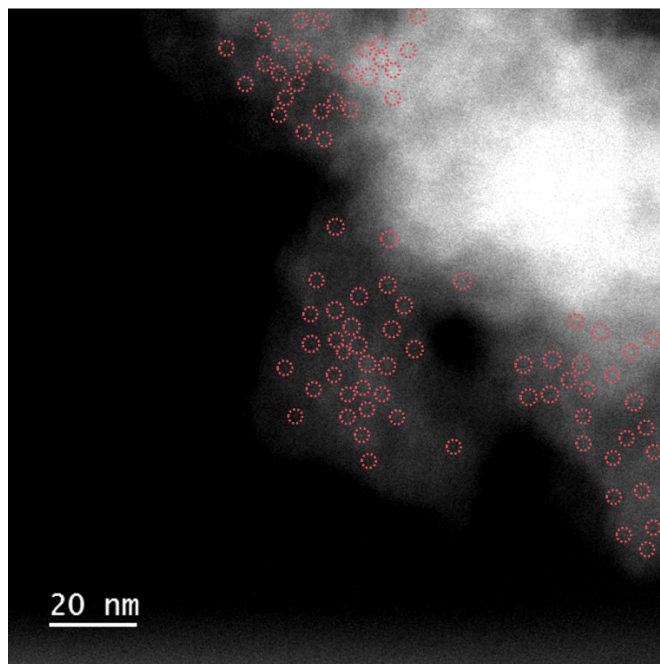


Figure S2. HAADF-STEM of Fe-N-C.

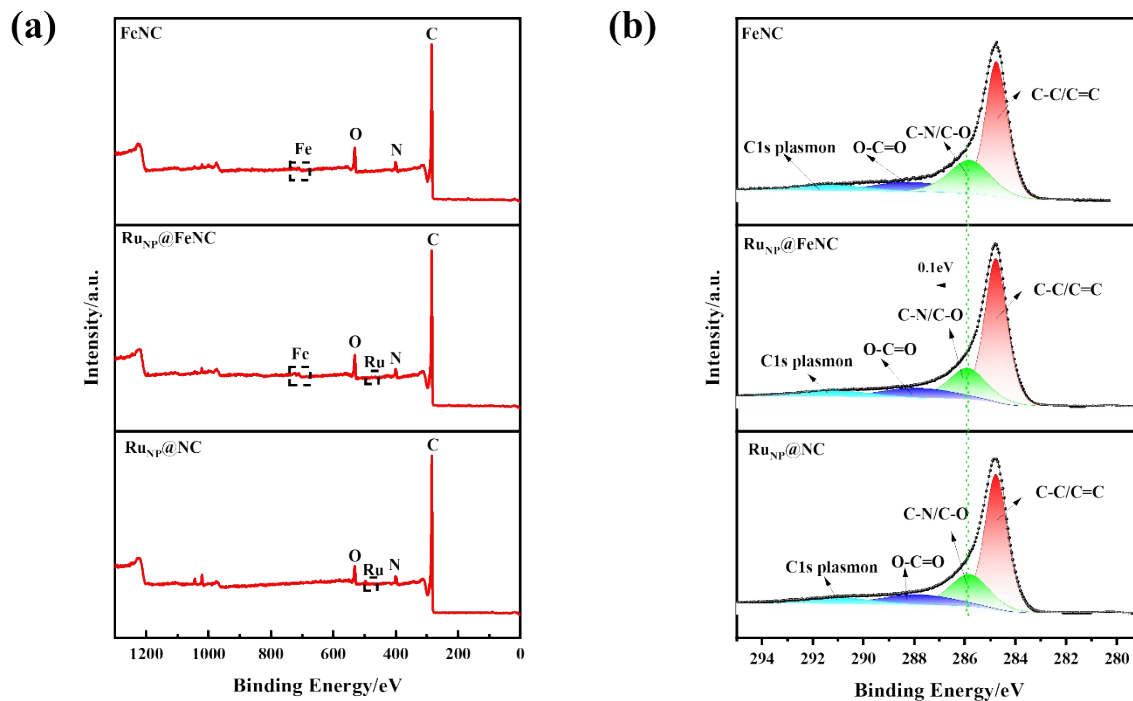


Figure S3. (a) XPS survey spectra and (b) C 1s spectra of Ru_{NP}@FeNC, FeNC, Ru_{NP}@NC.

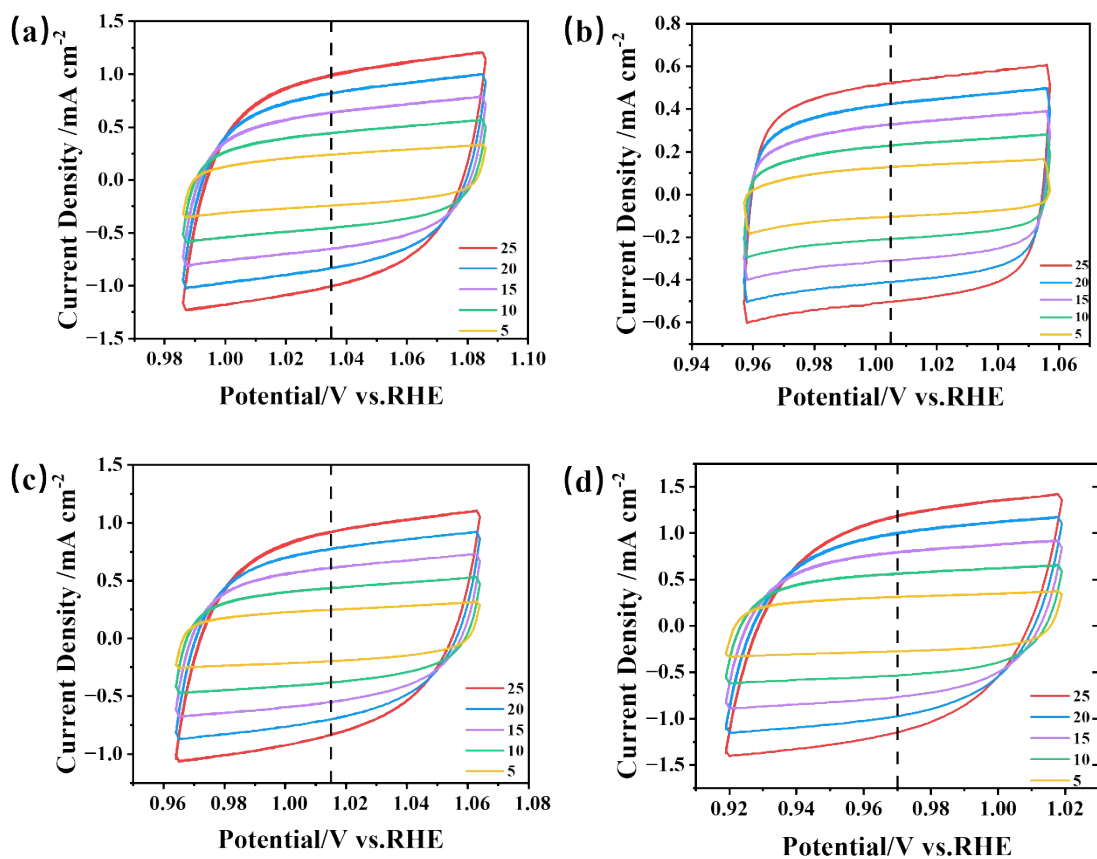


Figure S4. ECSA of (a) Ru_{NP}@FeNC, (b) FeNC, (c) Ru_{NP}@NC, (d) NC.

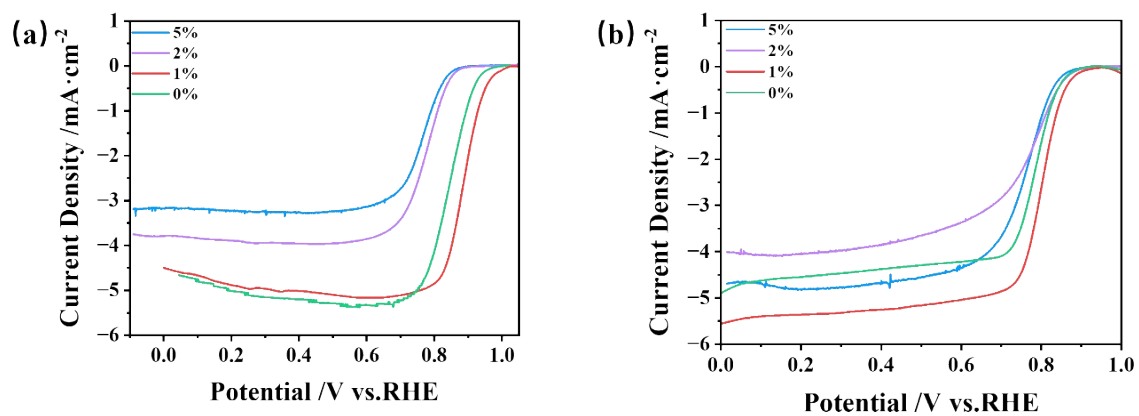


Figure S5. Polarization curves in O₂-saturated 0.1 M KOH(a) and 0.1 M HClO₄ (b) solution at 1600 rpm.

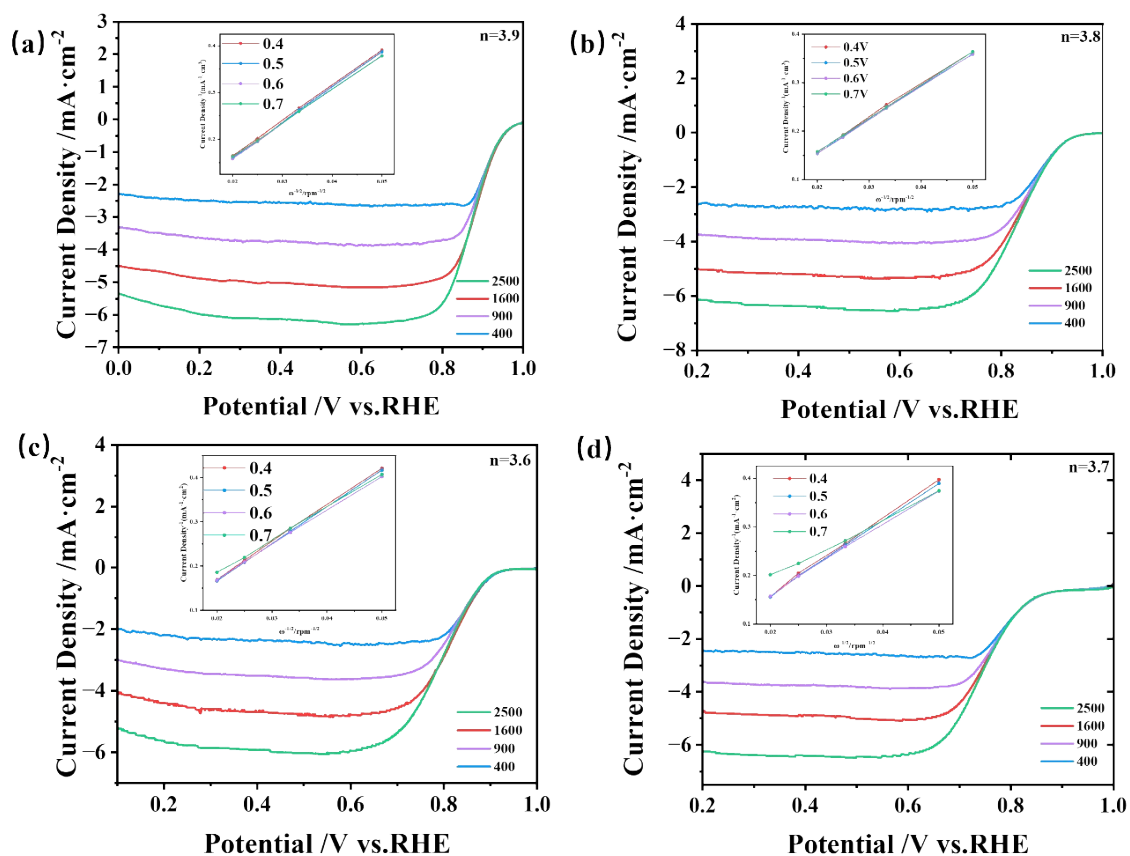


Figure S6. LSV in O_2 -saturated 0.1 M KOH and K-L curves of (a) $\text{Ru}_{\text{NP}}@\text{FeNC}$, (b) FeNC, (c) $\text{Ru}_{\text{NP}}@\text{NC}$, (d) NC.

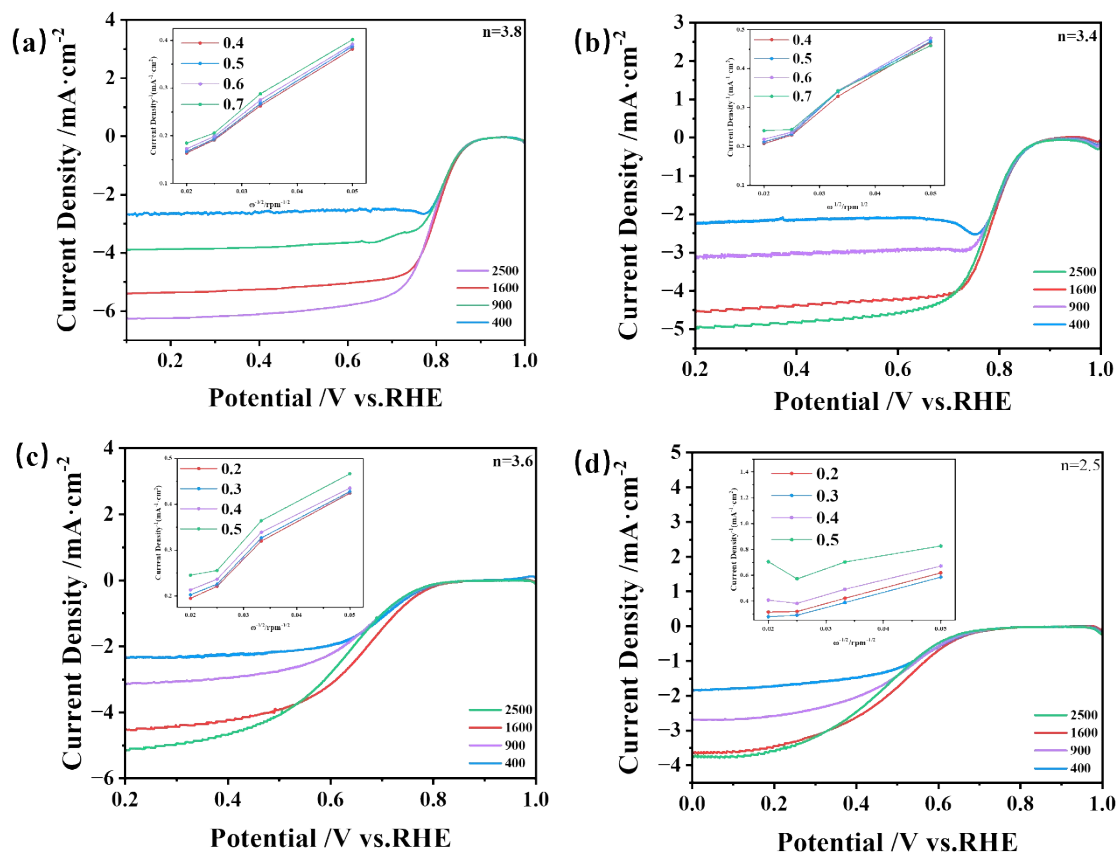


Figure S7. LSV in O_2 -saturated 0.1 M HClO_4 and K-L curves of (a) $\text{Ru}_{\text{NP}}@\text{FeNC}$, (b) FeNC , (c) $\text{Ru}_{\text{NP}}@\text{NC}$, (d) NC .

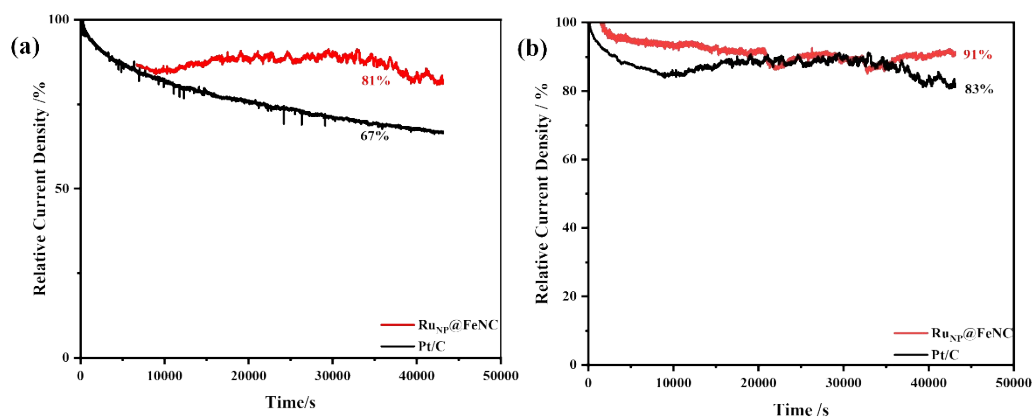


Figure S8. Chronoamperometric curves of Pt/C, Ru_{NP}@FeNC at a rotation rate of 900 rpm in O₂-saturated 0.1 M HClO₄ (a) and 0.1 M KOH (b) at 0.70 V for 50,000 s.

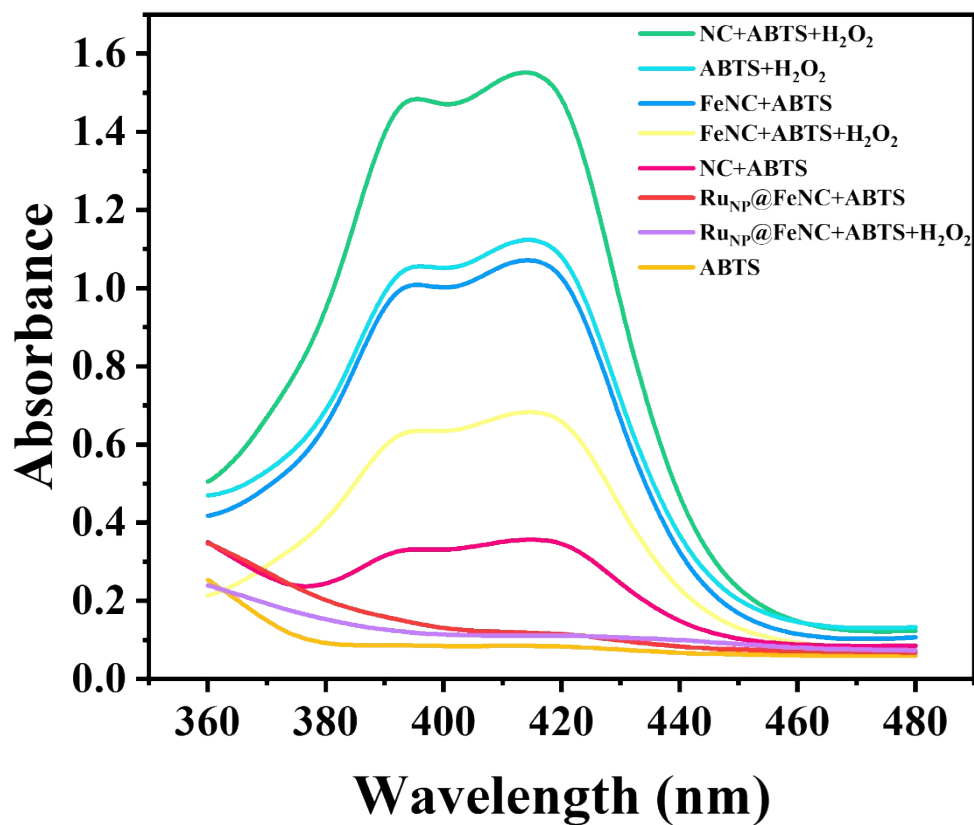


Figure S9. UV-vis spectra obtained by ABTS radicals capture test.

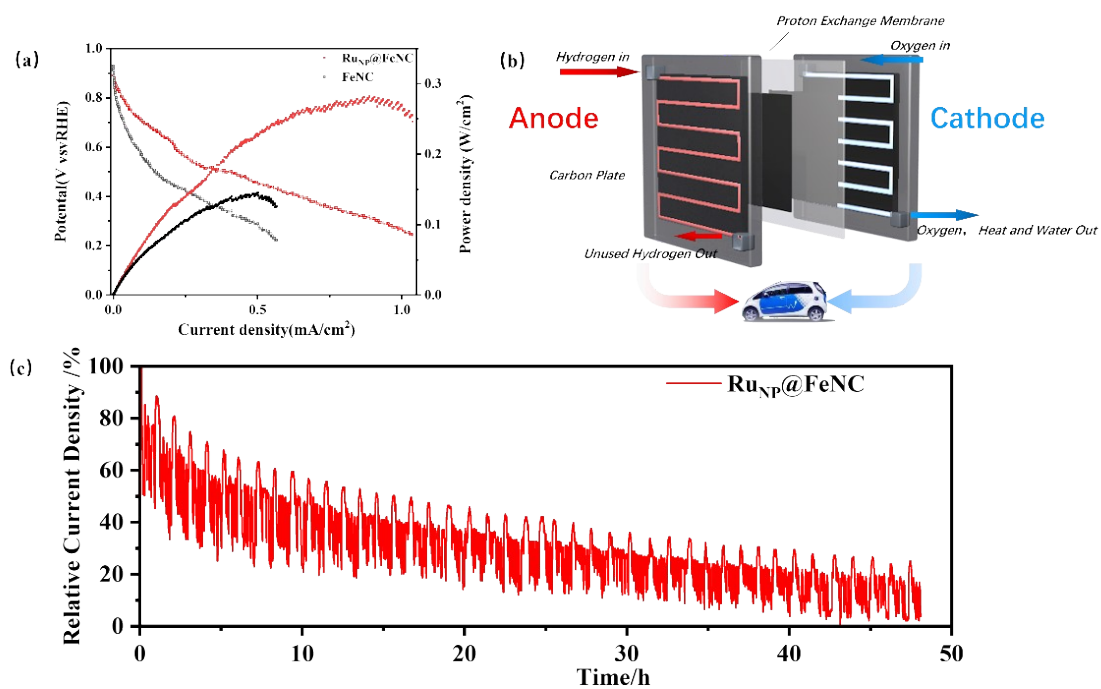


Figure S10. (a) The polarization curves and power density of Ru_{NP}@FeNC. (b) The mode of Proton exchange membrane fuel cell. (c) Stability test of H₂-O₂ fuel cell at a constant voltage of 0.6 V with Ru_{NP}@FeNC as cathode catalyst.

Table S1. I_D/I_G of different ratios of precursors.

Sample	I_D/I_G
Ru_{NP}@FeNC	1.21
FeNC	1.21
Ru_{NP}@NC	1.30
NC	1.24

Table S2. Specific surface area of catalyst.

Sample	BET (m²/g)	BJH (m²/g)	Dr (m²/g)	Pore volume (cc/g)	Average half aperture (nm)
Ru_{NP}@FeNC	1204.3185	81.1116	1311.5038	0.716794	1.19
FeNC	915.4467	142.9801	945.4902	0.821949	1.8
Ru_{NP}@NC	1032.7341	48.1433	1053.9542	0.591569	1.15
NC	1913.7137	81.4465	2029.3197	1.127365	1.18

Table S3. XPS and peak calculation results of catalyst.

Sample (Atomic %)	Ru_{NP}@FeNC	FeNC	Ru_{NP}@NC	NC
Carbon	89.11	88.59	90.25	87.81
Nitrogen	3.71	3.91	4.28	4.22
Oxygen	5.90	6.27	4.93	7.35
Iron	0.36	0.24	-	0
Ruthenium	0.02	0	0.03	0

Table S4. Binding energy (eV) of N species in the sample series from XPS measurements.

	Ru_{NP}@FeNC	FeNC
Carbon	90.25	87.81
Nitrogen	4.28	4.22
Oxygen	4.93	7.35
Iron	-	0
Ruthenium	0.03	0

Table S5. Fe 2p_{3/2} and binding energy (eV) of the sample series.

	Ru_{NP}@FeNC	FeNC
Fe-N_x 2p_{3/2}	708.19	709.44
Fe²⁺ 2p_{3/2}	709.99	710.73
Fe³⁺ 2p_{3/2}	711.72	711.92
Fe²⁺ shake-up	714.49	714.61
Fe³⁺ shake-up	716.99	719.52
