Supporting Information

Synthesis of IrCu/Co_3O_4 hybrid nanostructures and their enhanced catalytic properties toward oxygen evolution reaction under both acidic and alkaline conditions

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1. **Electrochemical Characterization.**

All electrochemical measurements were carried out at ambient temperature and pressure with an electrochemical workstation (CHI760E, Chenhua Shanghai). A three-electrode cell configuration was employed with a working electrode of glassy carbon with a working area of 0.07 cm^2, a counter electrode of graphite rod. The Hg/HgO (Re-61AP, ALS), and Ag/AgCl were the reference electrodes under the alkaline and acidic conditions, respectively. Electrocatalyst inks were prepared by dispersing 2 mg of catalyst into a solution containing 45 μL of 5% Nafion solution (Du Pont) and 555 μL of ultrapure water-ethanol solution with equal volumes of water and ethanol, followed by ultrasonication for 0.5 h. Before each experiment, the glassy carbon electrode was polished with 0.05 μm alumina for 0.2 h until it achieved a mirror shine. Then, 3.4 μL of the catalyst solution was transferred onto a glassy carbon electrode and fully dried at 25 °C.

The overpotential (η) was calculated by η = E(vs. RHE) – 1.23 V for OER. In addition, the 90% iR correction was done for the polarization curves. Electrochemical impedance spectroscopy (EIS) analysis was conducted at 1.50-1.65 V vs. RHE in the frequency range from 100 k to 0.01 Hz and the EIS plots were fitted using ZView software. To compare the electrochemically active surface area (ECSA) of each catalyst, the double-layer capacitance (C_{dl}) was measured in 1.0 M KOH (0.5 M H_2SO_4) in the non-Faradaic region at the scan rates of 20, 40, 60, 80, and 100 $mV \cdot s^{-1}$.

$$C_{dl} = (\Delta j = (j_a - j_c))/2 \qquad (1)$$

Turnover Frequency (TOF) is a measure of catalytic activity. It refers to the number of times a catalytic site converts a substrate into a product per unit time. It's a critical parameter for evaluating the efficiency of catalysts in chemical reactions[1].

$$TOF=I/4nF \qquad (2)$$

where I is the current density at a definite overpotential; F is the Faraday's constant (96,485 $C \cdot mol^{-1}$); and n, the number of moles of the electrochemical materials on the electrode. The factors 4 are based on the assumption that four electrons are necessary to form on oxygen molecules[2].

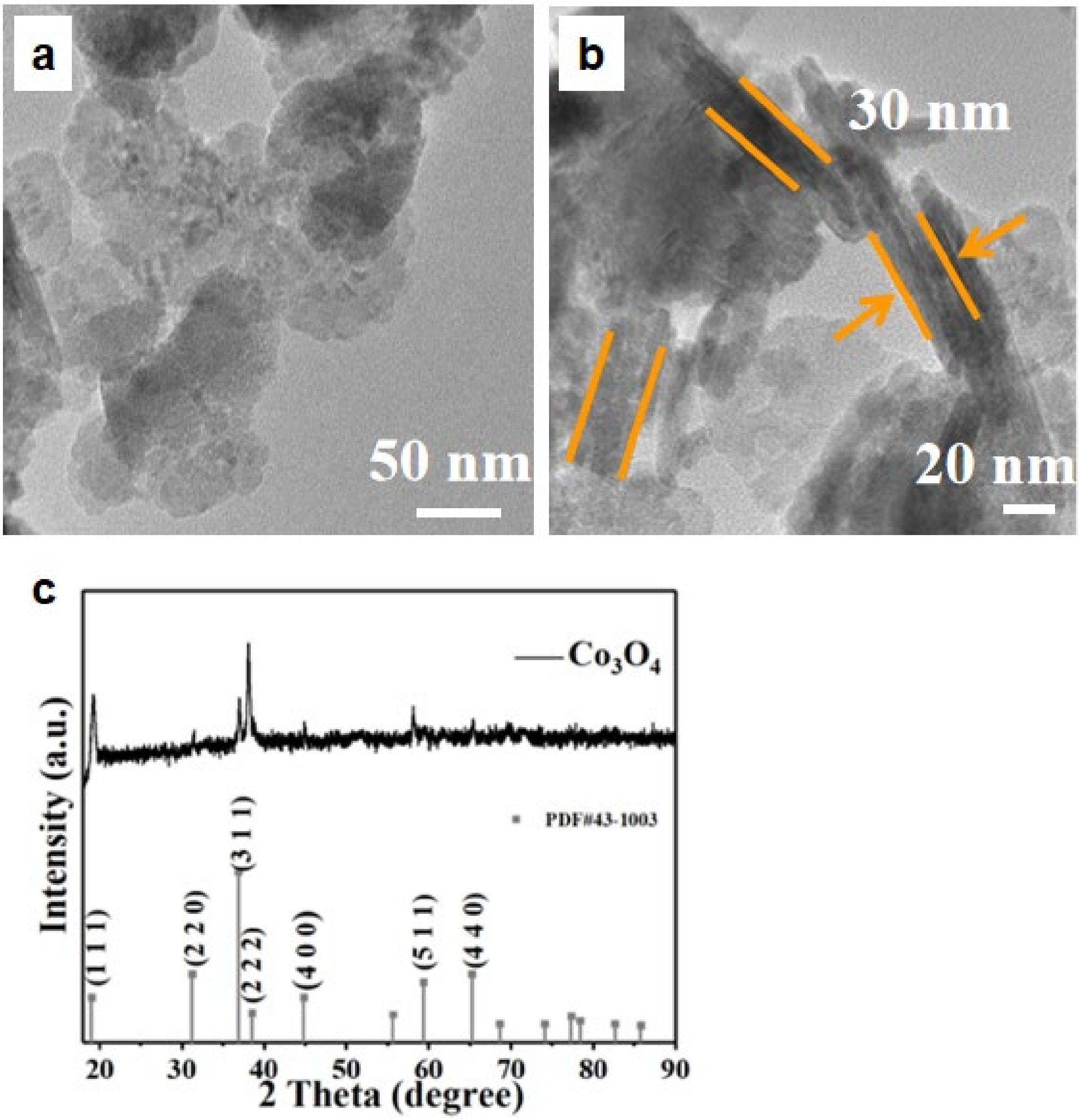

Fig. S1. (a and b) TEM images and (c) XRD patterns of Co_3O_4 nanosheets.

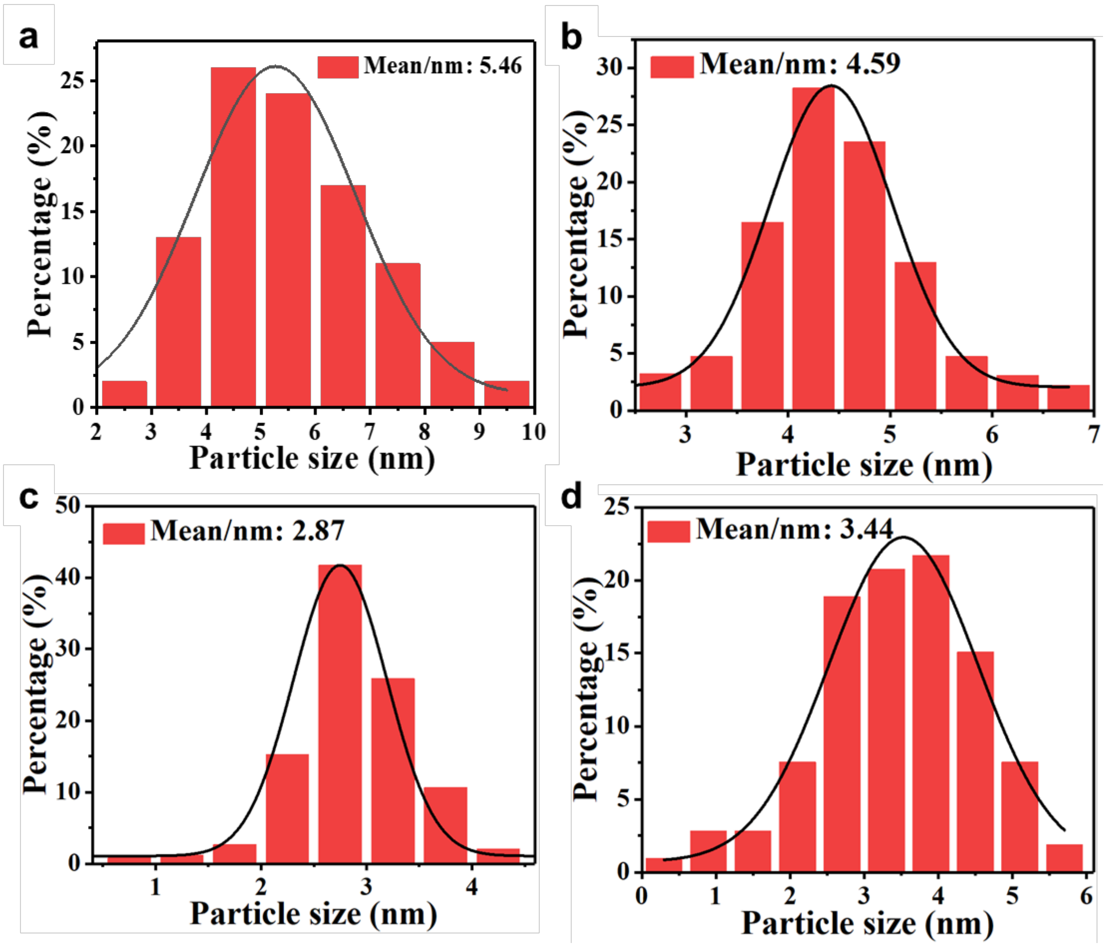

Fig. S2. Size distribution diagrams of the (a) $Ir_{26}Cu_{74}$ nanoparticles (b) $Ir_{19}Cu_{81}/Co_3O_4$, (c) $Ir_{26}Cu_{74}/Co_3O_4$, and (d) $Ir_{32}Cu_{68}/Co_3O_4$, respectively.

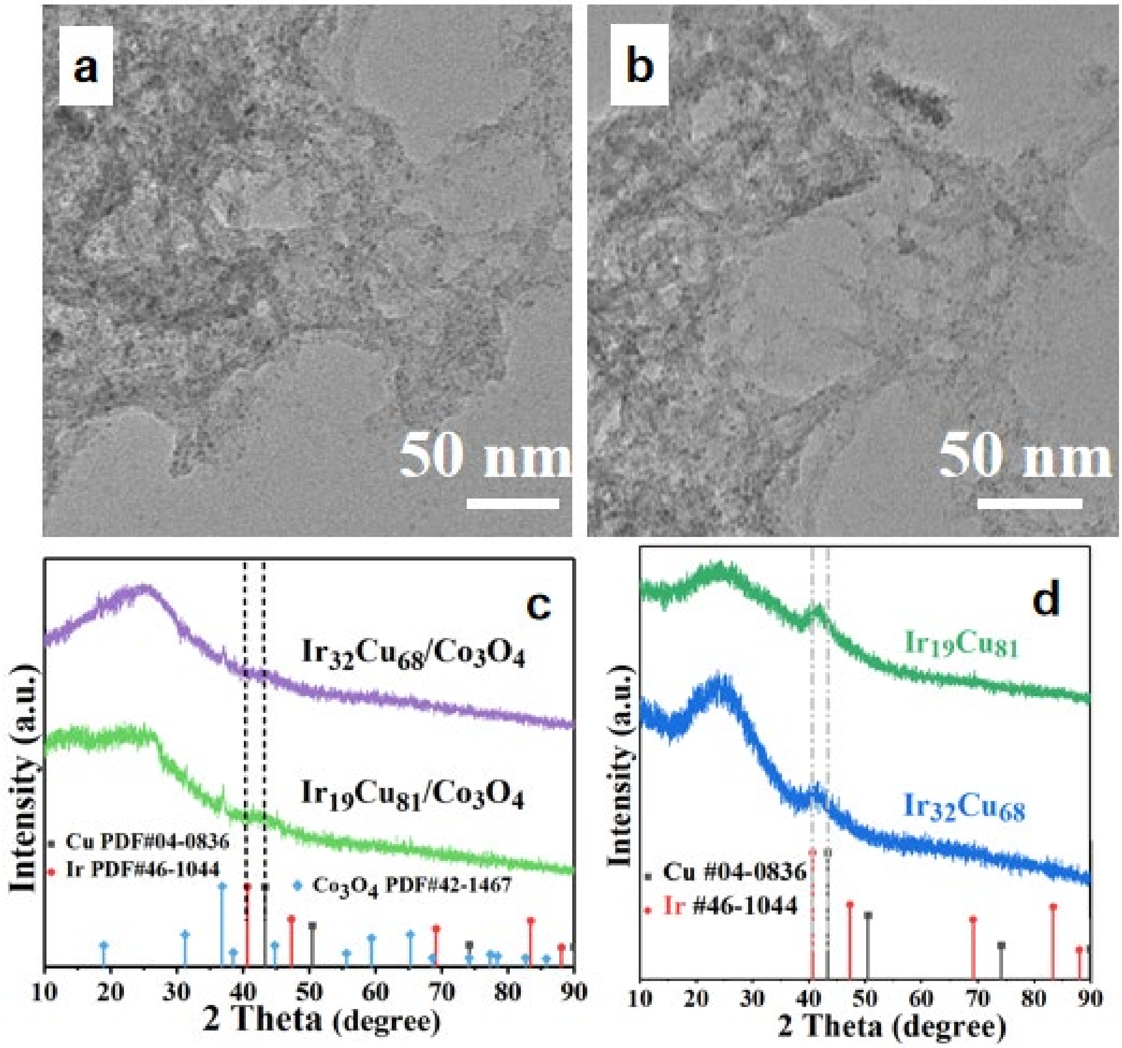

Fig. S3. TEM images of the (a) $Ir_{19}Cu_{81}/Co_3O_4$ and (b) $Ir_{32}Cu_{68}/Co_3O_4$. (c) XRD patterns of the $Ir_{19}Cu_{81}/Co_3O_4$ and $Ir_{32}Cu_{68}/Co_3O_4$. (d) XRD patterns of the $Ir_{19}Cu_{81}$ and $Ir_{32}Cu_{68}$.

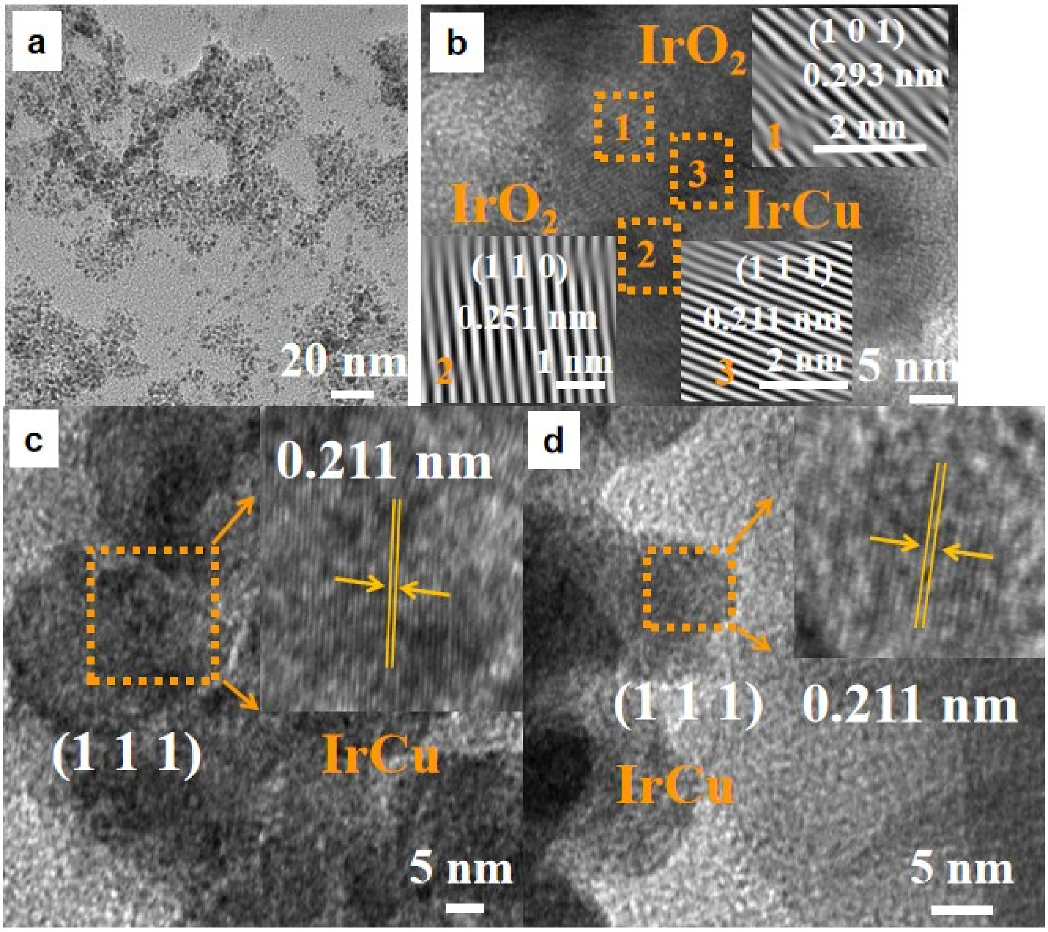

Fig. S4. (a) TEM and (b, c, d) HRTEM images of the $Ir_{26}Cu_{74}$ nanoparticles

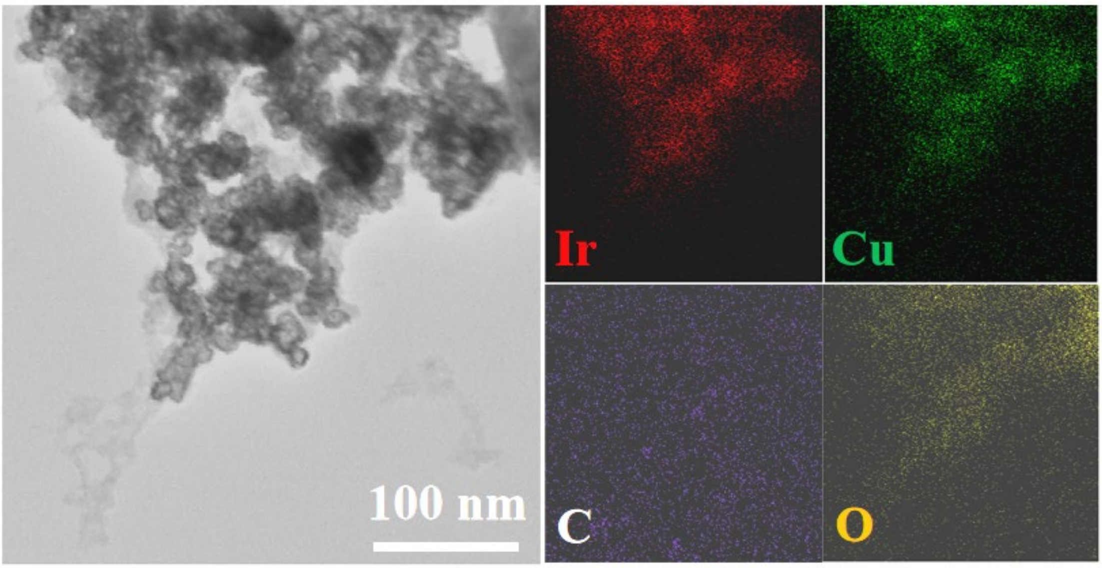

Fig. S5. TEM EDS Mapping images of the $Ir_{26}Cu_{74}$ NPs.

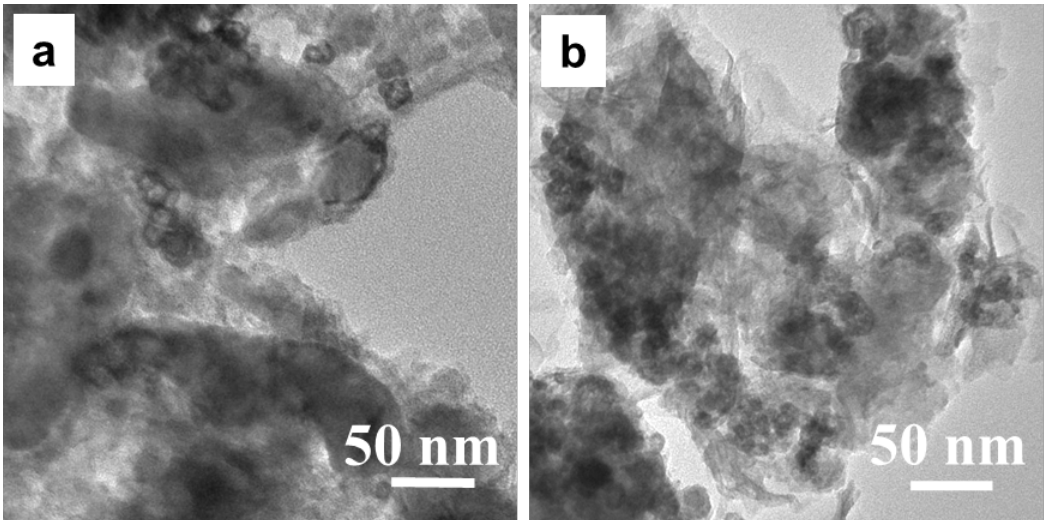

Fig. S6. TEM images of the $Ir_{26}Cu_{74}/Co_3O_4$ after OER stability test in (a) 1.0 M KOH and (b) 0.5 M H_2SO_4 solutions, respectively.

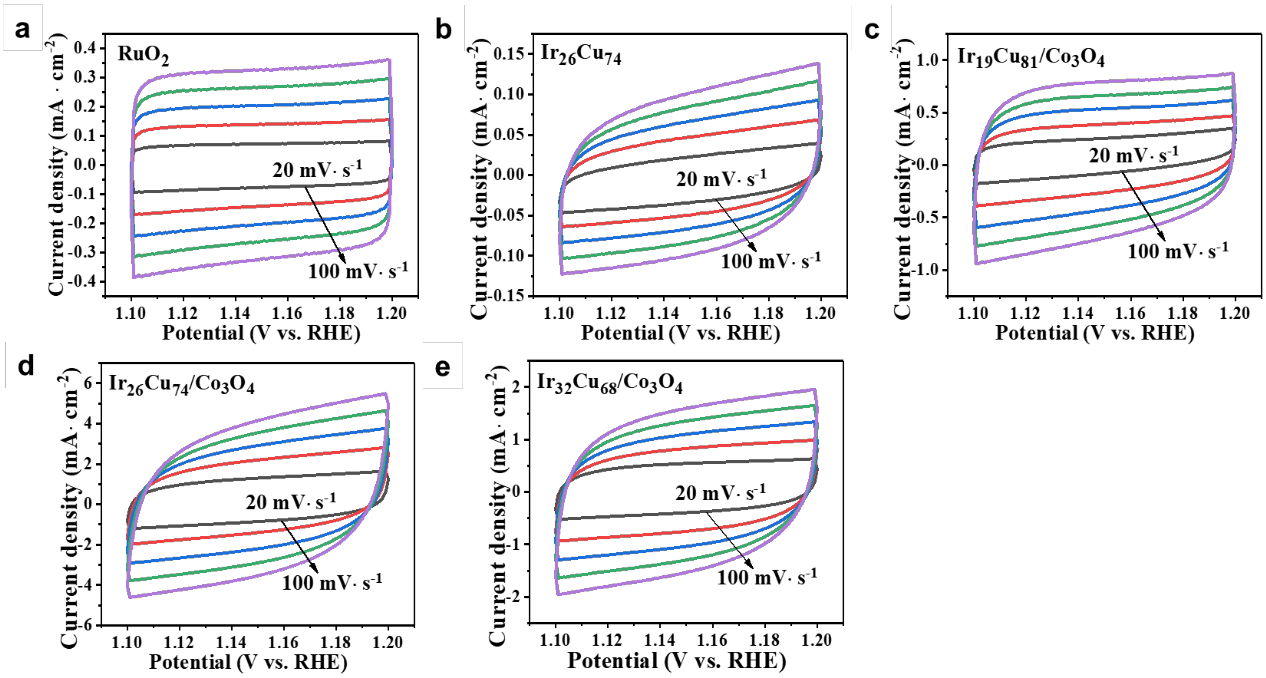

Fig. S7 CV curves of the (a) commercial RuO_2, (b) $Ir_{26}Cu_{74}$, (c) $Ir_{19}Cu_{81}/Co_3O_4$, (d) $Ir_{26}Cu_{74}/Co_3O_4$, and (e) $Ir_{32}Cu_{68}/Co_3O_4$ at different scan rates in a 1.0 M KOH solution.

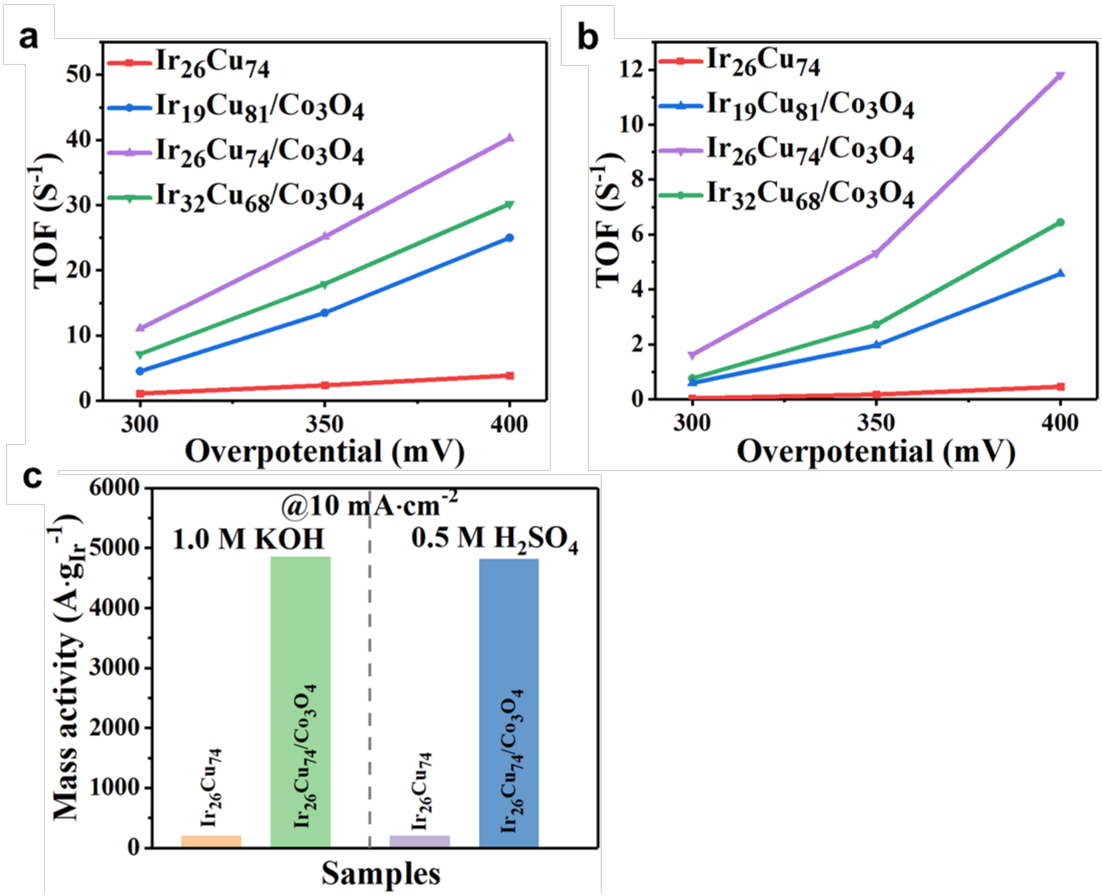

Fig. S8. TOFs of the $Ir_{26}Cu_{74}$, $Ir_{19}Cu_{81}/Co_3O_4$, $Ir_{26}Cu_{74}/Co_3O_4$, and $Ir_{32}Cu_{68}/Co_3O_4$ calculated in an (a) alkaline and (b) acidic conditions, respectively. (c) Mass activity of the $Ir_{26}Cu_{74}$ and $Ir_{26}Cu_{74}/Co_3O_4$.

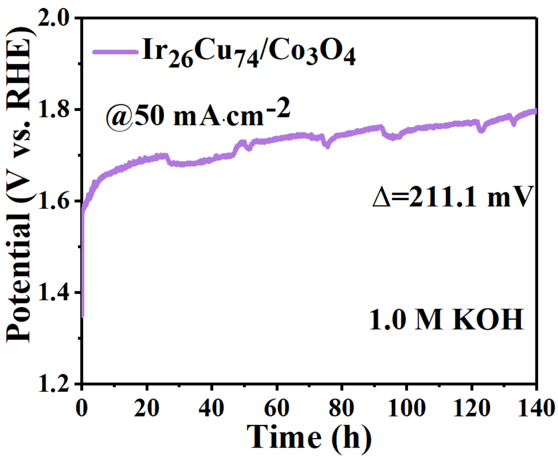

Fig. S9. Durability of the $Ir_{26}Cu_{74}/Co_3O_4$ in a 1.0 M KOH solution.

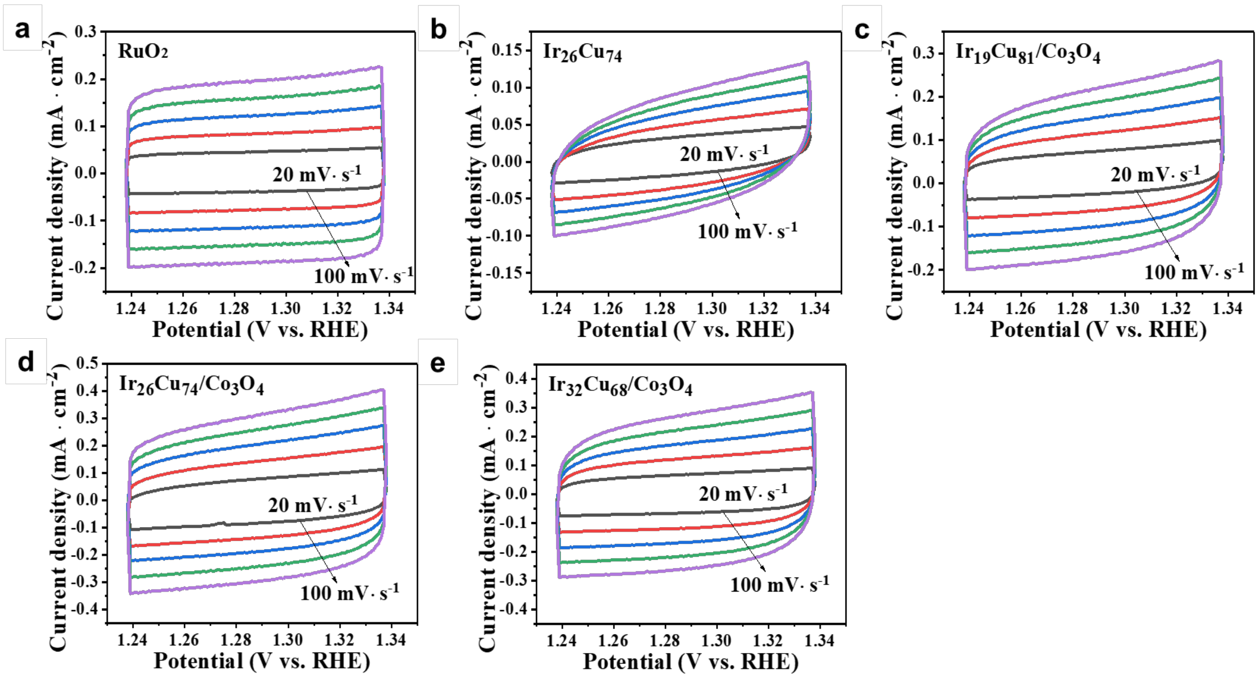

Fig. S10. CV curves of the (a) commercial RuO_2, (b) $Ir_{26}Cu_{74}$, (c) $Ir_{19}Cu_{81}/Co_3O_4$, (d) $Ir_{26}Cu_{74}/Co_3O_4$, and (e) $Ir_{32}Cu_{68}/Co_3O_4$ at different scan rates in a 0.5 M H_2SO_4 solution.

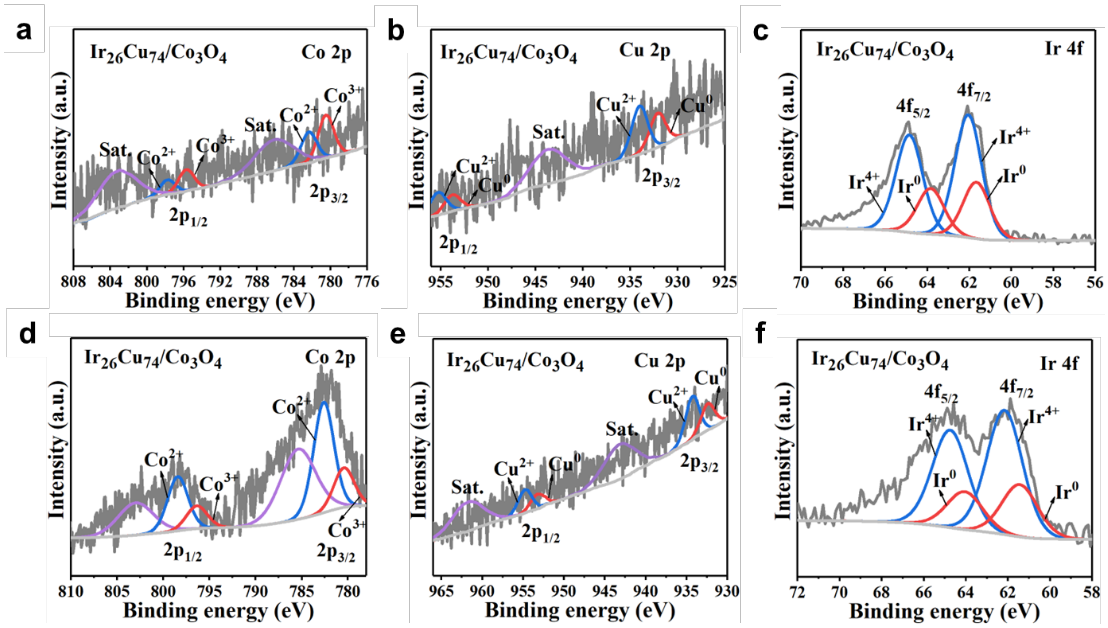

Fig. S11. XPS spectra of the $Ir_{26}Cu_{74}/Co_3O_4$ after OER stability test in an (a to c) alkaline and (d to f) acidic conditions, respectively.

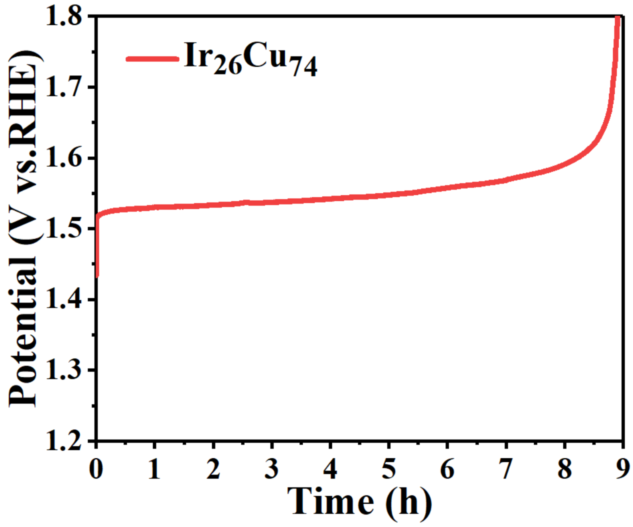

Fig. S12. OER stability test result of the $Ir_{26}Cu_{74}$ in a 1.0 M KOH solution

Table S1. ICP data of the IrCu/Co_3O_4.

Samples	C_{Ir}（mg/mL)	C_{Cu}（mg/mL)	Ir, Cu Mole ration
$Ir_{19}Cu_{81}/Co_3O_4$	0.87	1.23	0.23:1
$Ir_{26}Cu_{74}/Co_3O_4$	1.24	1.16	0.36:1
$Ir_{32}Cu_{68}/Co_3O_4$	1.50	1.13	0.47:1

Table S2. XPS data of the $Ir_{26}Cu_{74}$, $Ir_{26}Cu_{74}/Co_3O_4$, and Co_3O_4.

Samples/ Binding Energy (eV)	$Ir_{26}Cu_{74}$	$Ir_{26}Cu_{74}/Co_3O_4$	Co_3O_4
Ir^0 4f 7/2	60.78	60.98	/
Ir^0 4f 5/2	63.58	63.90	/
Ir^{4+} 4f 7/2	61.87	61.88	/
Ir^{4+} 4f 5/2	64.58	64.78	/
Cu^0 2p 3/2	932.18	932.28	/
Cu^0 2p 1/2	951.98	952.28	/
Cu^{2+} 2p 3/2	933.98	934.88	/
Cu^{2+} 2p 1/2	953.88	954.68	/
Co^{2+} 2p 3/2	/	781.78	782.48
Co^{2+} 2p 1/2	/	796.98	797.88
Co^{3+} 2p 3/2	/	780.38	780.48
Co^{3+} 2p 1/2	/	795.38	796.58

Table S3. OER performances of electrocatalysts in a 1.0 M KOH solution.

Catalysts	Electrolyte	OER(mV)@ j(mA/cm^2)	Tafel slope (mV·dec^{-1})	References
$Ir_{26}Cu_{74}$	**1.0 M KOH**	**263.1@10**	**82.3**	**This work**
	1.0 M KOH	**283.1@20**		
	1.0 M KOH	**328.2@50**		
$Ir_{19}Cu_{81}/Co_3O_4$	**1.0 M KOH**	**264.9@10**	**77.9**	**This work**
	1.0 M KOH	**282.1@20**		
	1.0 M KOH	**310.9@50**		
$Ir_{26}Cu_{74}/Co_3O_4$	**1.0 M KOH**	**255.9@10**	**67.5**	**This work**
	1.0 M KOH	**268.1@20**		
	1.0 M KOH	**287.1@50**		
$Ir_{32}Cu_{68}/Co_3O_4$	**1.0 M KOH**	**256.1@10**	**75.1**	**This work**
	1.0 M KOH	**271.1@20**		
	1.0 M KOH	**296.5@50**		
Ir-Co_3O_4@NC	1.0 M KOH	296.0@10	89.0	[3]
$Pt_3Rh–Co_3O_4$/C	1.0 M KOH	290 .0@10	63.4	[4]
5-Ir-NCO	1.0 M KOH	348.0@10	103.0	[5]
IrCo–N–C	0.1 M KOH	330.0@10	79.0	[6]
Ir-TrEGO	1.0 M KOH	338.0@10	127.7	[7]
IrO_2@Ir-MOF	1.0 M KOH	283.0@10	110.6	[8]

IrCo NRAs	1.0 M KOH	257.3@10	70.1	[9]
IrO_2/NF	1.0 M KOH	292.0@10	60.7	[10]
Ir nanochains	1.0 M KOH	340.0@10	125.0	[11]

Table S4. OER performances of noble metal based electrocatalysts in a 0.5 M H_2SO_4 electrolyte.

Catalysts	Electrolyte	OER(mV)@ *j*(mA/cm^2)	Tafel slope (mV·dec^{-1})	References
$Ir_{26}Cu_{74}$	**0.5 M H_2SO_4**	**387.0@10**	**296.4**	**This work**
	0.5 M H_2SO_4	**434.9@20**		
$Ir_{19}Cu_{81}/Co_3O_4$	**0.5 M H_2SO_4**	**334.9@10**	**191.8**	**This work**
	0.5 M H_2SO_4	**369.1@20**		
$Ir_{26}Cu_{74}/Co_3O_4$	**0.5 M H_2SO_4**	**293.0@10**	**165.3**	**This work**
	0.5 M H_2SO_4	**317.1@20**		
$Ir_{32}Cu_{68}/Co_3O_4$	**0.5 M H_2SO_4**	**317.0@10**	**182.9**	**This work**
	0.5 M H_2SO_4	**345.9@20**		
IrO_2/Co_3O_4	0.5 M H_2SO_4	452.0@10	114.4	[12]
Ir_1-Co_3O_4-NS-300	0.5 M H_2SO_4	505.0@10	129.3	[13]
$IrCoO_x$@LLCF	0.1 M $HClO_4$	286 ± 5@10	47.3 ± 2	[14]
IrO_2@Co_3O_4	0.5 M H_2SO_4	301.0@10	72.1	[15]
IrCoNi PHNCs	0.5 M H_2SO_4	309.0@10	/	[16]
Ir(20)/Fe@NCNT-900	0.5 M H_2SO_4	300.0@10	64.5	[17]
$Rh_{22}Ir_{78}$	0.5 M H_2SO_4	300.0@10	/	[18]
HM-IrO_2	0.5 M H_2SO_4	312.0@10	61.2	[19]
C−IrO_2	0.5 M H_2SO_4	308.0@10	87.7	[20]

Ir/G	0.5 M H_2SO_4	389.0@10	126.6	[21]

Table S5. ICP data of the $Ir_{26}Cu_{74}/Co_3O_4$ post OER in alkaline and acidic conditions.

Samples	C_{Ir}（mg/mL)	C_{Cu}（mg/mL)	C_{Co}（mg/mL)	Mole ration
$Ir_{26}Cu_{74}/Co_3O_4$ (1.0 M KOH)	0.885	0.036	2.845	$Ir_{89}Cu_{11}$
$Ir_{26}Cu_{74}/Co_3O_4$ (0.5 M H_2SO_4)	0.950	0.031	3.367	$Ir_{91}Cu_9$

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