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2022-10-28

A Self-Supported Ru-Cu3P Catalyst toward Alkaline Hydrogen

Evolution

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 Alkaline Hydrogen Evolution

-Xuan Wan[#], Chao-Hui Wang[#] Zi-Xuan Wan# 电 化 学

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 cd Ru-Cu₃P Catalyst toward
 Hydrogen Evolution

¹, Chao-Hui Wang^{*}, Xiong-Wu Kang^{*}
 ool of Environment $\begin{array}{lll} &\mbox{if}&\nolimits\&\$ $[Article] \begin{tabular}{c} {\footnotesize \begin{tabular}{l} \bf 1. \textit{Electrochem. 2022, 28(10), 2214005 (1 of 9)} \end{tabular} } \\ \hline \end{tabular} \end{tabular} \begin{tabular}{c} (Article) \label{tab:2} \bf 2. \textit{B} \end{tabular} \end{tabular} \begin{tabular}{c} \bf 3. \textit{E} \end{tabular} \begin{tabular}{c} \bf 4. \textit{E} \end{tabular} \end{tabular} \begin{tabular}{c} \bf 5. \textit{E} \end{tabular} \begin{tabular}{c} \bf 6$

 $\begin{array}{ll} \text{\#} & \text{\#} & \text{\#} \\ \text{\#} & \text{\#} & \text{\#} \\ \text{DOE: 10.13208/j. electrochem. 2214005} & \text{Htp://electrochem.xmu.eduon}) \\ \text{\#} & \text{Mw1d} & \text{Alkaline Hydrogen Evolution} \\ & \text{Alkaline Hydrogen Evolution} \\ & \text{Zi-Xuan Wan}^s, \text{Chao-Hui Wang}^s, \text{Xionge-Wu Kang} \\ & \text{Energy Research Institute, School of Environment and Energy, South China University of Technology, Higher Education Mega Center, Guangzhou $10006, Guangalong, China) \\ \text{Turasiion metal phosphate (TMP)$ $\begin{array}{ll} \textbf{\textit{if}} & \textbf{\#} & \textbf{\#} \\ \textbf{\textit{L} \textit{E} \textit{f} \textit{et} \textit{c} \textit{c} \textit{d} \textit{c} \textit{d} \textit{d}$ **Line Electrochem.** 2022, 28(10), 2214005 (1 of 9)

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Zi-Xuan Wan[#], Chao $\begin{array}{ll} \text{\LARGEψ} & \text{\LARGEψ} \\ \hline \end{array} \begin{array}{ll} \text{\LARGEψ} & \text{\LARGEψ} \\ \text{A\textbf{X}} & \text{B} & \text{C} & \text{D} \\ \text{D0}: & 10.132085, \text{electrochem.} 2214005 \end{array} & \text{Hup/electrochem.} \text{xmu} \text{,} \text{du} \text{m} \\ \text{\LARGE$\mathbf{A} \textbf{Self-S} \textbf{L} \textbf{p} \textbf{p} \textbf{p} \textbf{p} \textbf{p$ *I. Electrochem.* 2022, 28(10), 2214005 (1 of 9)

DOI: 10.13208*j* electrochem.2214005
 A Self-Supported Ru-Cu₃P Catalyst toward
 A Kaline Hydrogen Evolution

Zi-Xuan Wan⁴, Chao-Hui Wang⁴, Xiong-Wu Kang²

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 A Self-Supported Ru-Cu₃P Catalyst toward
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Zi-Xuan Wan^g, Chao-Hui Wang^g, Xiong-Wu Kang^{*}

(New Energy Research Institute, School of Enciromment and Energy, South China Uni **A Self-Supported Ru-Cu₃P Catalyst toward

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Te A Self-Supported Ru-Cu₃P Catalyst toward**
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(New Energy Research Institute, School of Environment and Energy, South China University of

Te Example 16 Ru-Cu₃P Catalyst toward**
 e Hydrogen Evolution

1^{*n*}, Chao-Hui Wang[#], Xiong-Wu Kang[#]
 Mega Center, Guanghou 510006, Guangdong, China)
 a kind of effective catalysts toward hydrogen evolution react **Example 18 Society Altaline Hydrogen Evolution**
 Altaline Hydrogen Evolution

(New Energy Research Institute, School of Environment and Energy, Social China University of

Technology, Higher Education Mega Center, Guar **ALKENINE HYGTOGEN EVOILLION**

Zi-Xuan Wan[#], Chao-Hui Wang[#], Xiong-Wu Kang^{*}

(New Energy Research Institute, School of Ensimment and Energy, South China University of

Technology, Higher Education Mega Center, Guang Zi-Xuan Wan^e, Chao-Hui Wang^e, Xiong-Wu Kang^e
(New Energy Research Institute, School of Environment and Energy, South China University of
Technology, Higher Education Mega Center, Guangahou 510006, Guangdong, China)
 Zi-Xuan Wan", Chao-Hui Wang", Xiong-Wu Kang"

(New Energy Research Institute, School of Encironment and Energy, South China University of

Technology, Higher Education Mega Center, Guangchou 510006, Guangchoug, China)

Ab **ISSUME Transition metal phosphide (TMP)** is a kind of effective catalysts toward hydrogen evolution reaction (IIER) in alka-
electrolytes. However, the performance of TMP catalysts is strongly limited by water splitting. **Abstract:** Transition metal phosphide (TMP) is a kind of effective catalysis toward hydrogen evolution reaction (IIER) in alia-
time sectrolytes. However, the performance of TMP etalytys is strongly limited by varies equ line electrolytes. However, the performance of TMP catalysts is stongly limited by water splitfing. In this work, we developed a
method to requent a conjers fram (CF) supported Ru-deped CMP ediaty (Ru-CMP/RC) by a concent method to prepare a corper fram (CF) supported Ru-doped CuP estabyt (Ru-CuP/CF) by a consecutive growth of Cu(OH)₃ nanoary-
any exacting in RaCl₃, continue and phosphorization. A large surface area was obtained by the enys, soaking in RaCl, solution and phosphorization. A large surface area was obtained by the self-surperted cauliyes with the oppopriative Ru doing. As a recellent HER cents HER denote the May is considered as a potential oppoprimalis e Ra doping As an excellent HER eat
highed a low overpotential of 95.6 mV at a current density of 10
mA-cm', which is much as the simulation of the field slope was changed from Volmer step to Higrovsky sign. mA com', which is 1494 mV lower than that of CupPCt without Ru-doping The Tacklishey as a context throm life. On 736 mA doc'

and the rate determining step was changed from Volmer step to Heyrowky step. The improvement of production rates of hydrogen^[4], which reduces the en-
hyst (Ru-Cu₃P/CF) by a consecutive growth of Cu(OH)₂ nanoar-
exerca area was obtained by the self-supported catalysts with the
d a low overpotential of 95.6 mV a er catalysts toward hydrogen evolution reaction (HER) in alka-
ongly limited by water splitting. In this work, we developed a
dyst (Ru-Cu₃P/CF) by a consecutive growth of Cu(OH)_z nanoar-
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ongly limited by water splitting. In this work, we developed a
hyst (Ru-Cu₃P/CF) by a consecutive growth of Cu(OH)₂ nanoar-
ce area was obtained by the se ongly limited by water splitting. In this work, we developed a
dyst (Ru-Cu₃P/CF) by a consecutive growth of Cu(OH), nanoar-
ce area was obtained by the self-supported catalysts with the
d a low overpotential of 95.6 mV a reguy mincut o wate spirang. in this work, we develope a
singly muster spiral paramign in this work, we develope a
reactive growth of Cu(OH), nana-
ee area was obtained of 95.6 mV at a current density of 10
oping. The Tafe

1 Introduction production rates of hydrogen^{ts}, which reduces the en-

It is imminant to develop renewable energy to alle-

its imminant to develop renewable emergy to alle-

videoper production^[5]. In order to reduc It is imminent to develop renewable energy to alle-

orgy conversion efficiency and incuite environmental problems caused by consump-

the diplomary of reditional fossil finels. The totel the high ener-

overpotential and **Exp words:** electrocaulysis; water splitting; hydrogen evolution; corper phosphide; Ru-doping

1 **Introduction**

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1 **Introduction**

1 **Introduction**

1 **Interval as: We assume the contr** and the raise determining step was changed from Voiner step to Heyrovicy strp. The improvement of HER periomance mapline the matched to the development of HER periomatical variety of the Cu(OII), amays msured large electro attanous to the simulate water splitting step y to eloping, whan provides and a clear correst splitter. The ananopatical particular contents of the supercted electrodes, which could promote the mass and electron tarisfers, maripunagy is a tracking there is energy in the carbon free the system in the carbon content and proportion and halo be reach on the carbon production and halo be reach on the system in the carbon of the tuning of the wate From the determinant of the mining of the water splitting at particle and point and point and the transformation reaction of the mining of the water splitting at particle determination reaches the reaction for the big poi pare the road for design of high-performance HER electrocautyst.
 Key words: electrocautysis; water splitting; hydrogen evolution; coper phosphide; Ru-doping
 CATE ACTIVE TO EXECUTE TO EXECUTE THE CONSULTER THE CONSULT

1 Introduction **1** Introduction **1** Introduction **1** Introduction **1** Introduction ce area was obtained by the self-supported catalysts with the
d a low overpotential of 95.6 mV at a current density of 10
oping. The Tafel slope was reduced from 136.6 to 73.6 mA·dec⁻¹
grovides more active sites for wate d a low overpotential of 95.6 mV at a current density of 10
oping. The Tafel slope was reduced from 136.6 to 73.6 mA·dec⁻¹
rrovsky step. The improvement of HER performance might be
orovides more active sites for wate sp oping. The Tafel slope was reduced from 136.6 to 73.6 mA - dec⁻¹
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orovides more active sies for wate rsplitting. The nanoparticles
arge electrochemical surface are provsky step. The improvement of HER performance might be
provides more active sites for water splitting. The nanoparticles
arge electrochemical surface areas of the supported electrodes,
as production and bubble release. provides more active sites for water splitting. The nanoparticles
rarge electrochemical surface areas of the supported electrodes,
as production and bubble release. This work highlights the im-
ring by the transition metal electrocenemeal surface areas of the supported electroces,
reduction and bubble release. This work highlights the im-
by the transition metal with emptier d orbitals, which may
opper phosphide; Ru-doping
oduction rates of lysts production and stable. This work inguigate at all
tring by the transition metal with emptier d orbitals, which may
production rates of hydrogen^[6], which reduces the en-
ergy conversion efficiency and increases th copper phosphide; Ru-doping
production rates of hydrogen^[4], which reduces the en-
ergy conversion efficiency and increases the cost of
hydrogen production^[5]. In order to reduce reaction
overpotential and energy cons

 $#E\#(J. Electrochem.)$ 2022, 28(10), 2214005 (2 of 9)
sition metal compounds, such as hydroxides, sulfides, doping, due to the electron-deficient d orbitals of Ru,
selenides, and phosphides^[10]. Transition metal phos-
phides are **EVALUATION**
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sition metal compounds, such as hydroxides, sulfides, doping, due to the electron-deficient d orbitals of Ru,

selenides are considered as doping phosphor atoms

the latti $\# \&L^{\infty}(L \&Electrochem.)$
 $\qquad \qquad \# \&L^{\infty}(L \&Electrochem.)$ 2022, 28(10), 2214005 (2 of 9)

sition metal compounds, such as hydroxides, sulfides,

selenides, and phosphides^[10]. Transition metal phosphor indicating that this strat **EVALUATION**
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sition metal compounds, such as hydroxides, sulfides, doping, due to the electron-deficient d orbitals of Ru,

selenides, and phosphides¹⁹⁹. Transition met al atoms and promote the water splitting in alkaline **Example 19** EV Electrochem.) 2022, 28(10), 2214005 (2 of 9)

sition metal compounds, such as hydroxides, sulfides, doping, due to the electron-deficient d orbitals of Ru,

selenides, and phosphides¹⁰⁰. Transition metal **Example 19**

the HER process by station metal compounds, such as hydroxides, sulfides,

sition metal compounds, such as hydroxides, sulfides,

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sition metal compounds, such as hydroxides, sulfides,

phighlides are considered as doping $\frac{16}{2}$ cost and phospher and hos-

the lattice of t ± 0.22 , ± 0.22 activity is conductive transition that the state of transition metal phosphides, and phosp sition metal compounds, such as bivariates, sulfides,
sulfue to the electron-deficient d orbitals of Ru,
selenides, and phosphides^[60]. Transition metal phoss-indicating that this strategy is conductive transition
phide sition metal compounds, such as hydroxides, sulfides,

seleptides, and phosphides and phosphides and phosphides and phosphides are considered as doping phosphor atoms in email phosphides and beyond.

be lattice of transit

phides are considered as doping phosphor atoms into

metal phosphides and beyond.

the hattice of ransition metals¹⁶¹, where the phosphor

atoms can show the activity are the phosphor

atoms can also withdraw electros f the lattice of transition metals¹¹³, where the phosphor

atoms behave as H adsorption sites⁽¹³⁾. The phosphor

2.1 **Materials**

atoms can also withdraw electrons from the metals^[43]

atoms and promote the water mole atoms behave as II adsorption sites¹²¹. The phosphor

all reagents were used as received without further

atoms can also withdraw electrons from the metals¹¹⁹, all reagents were used as received without further

enhan atoms can also withdraw electrons from the metals^[13]. All reagents were used as received without further
enhance the adsorption of water molecules on the met-
equilication. Ruthenium trichloride (RuCl₃, 99%), po-
al enhance the adsorption of water molecules on the met-

and anomous the under splitting in alkaline clusterial of the water splitting in alkaline

solution. In an acidic electrolyte, phosphor can facili-

solution hypopolo al atoms and promote the water splitting in alkaline

sassium hydroxide (KOH, 95%), absolute ethanol

solution. In an actioc electrolyte, phosphor can facili-

cate the HFR process by enhancing the adsorption of

solution $mA \cdot cm^{-2}$. the HER process by enhancing the adsorption of

sodium hypophosphite (NaH₂PO₃, 98%), annonium

ittivity charged protons on phosphor atoms^[60]. (Cl.17%) were purchased from Energy Chemical

symbide (Cu_BP) is consid positively charged protons on phosphor atoms¹¹⁴.

Among the transition metal phosphide (Cu_P) is considered as an ideal material

co. Copper from Parey Chemical

phosphide (Cu_P) is considered as an ideal material

fo Among the transition metal phosphides¹⁹³, copper

(HCl, 37%) were purchased from Energy Chemical

phosphide (Cu_P) is considered as an ideal materal co. Copper foam (10 cm × 10 cm) was purchased from

for development o

wire arrays by low temperature phosphorization reac-

ion, which needs an overpotential of 143 mV (vs.

impurities or oxides. The cleaned CF (1 cm × 1 cm)

RHE) to achieve a caulytic current density of 10

was instantly i tion, which needs an overpotential of 143 mV (vs.

HPHF) to achieve a catalytic current density of 10 was instantly immersed into a 10 mL aqueous solu-

RHF) to achieve a catalytic current density of 10 was instantly imme RHE) to achieve a catalytic current density of 10

mA·cm³.

The alkaline HER activity of the most reported

for 2 min to obtain Ru-CI

Cu_PP catalyts is still limited by the water disocia-

for 2 min to obtain Ru-CI

t **1.** cm⁻². the altaline HER activity of the most reported for 2 min to obtain Ru-CF. 0.3 g NaH-PO, and Ru-CF

The altaline HER activity of the most reported that transition were alt at two adjacent procedure based wit The alkaline HER activity of the most reported

for 2 min to obtain Ru-CF. 0.3 g NaII₂PO₂ and Ru-CF

Cu₃P catalysts is still limited by the water dissocia-

to neep put at two adjacent porcelain boas, at the up-

tr CusP catalysts is still limited by the water dissocia-
were put at two adjacent porcelain boats, at the up-
ton step. It has been widely reported that transition stream and downstream of tube furnace, respectively.
the me

28(10), 2214005 (2 of 9)
doping, due to the electron-deficient d orbitals of Ru,
indicating that this strategy is conductive transition
metal phosphides and beyond.
2 Experimental Section $\frac{1}{28(10), 2214005 (2 \text{ of } 9)}$
doping, due to the electron-deficient d orbitals of Ru,
indicating that this strategy is conductive transition
metal phosphides and beyond.
2. Experimental Section
2.1 Materials $(28(10), 2214005 (2 \text{ of } 9))$

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indicating that this strategy is conductive transition

metal phosphides and beyond.
 2. Experimental Section
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doping, due to the electron-deficient d orbitals of Ru,

indicating that this strategy is conductive transition

metal phosphides and beyond.
 **2 Experimental Section

2.1 Materials**

All reagent 电化学(*J. Electrochem.*) 2022, 28(10), 2214005 (2 of 9)

shydroxides, sulfides, doping, due to the electron-deficient d orbitals of Ru,

ransition metal phos-

indicating that this strategy is conductive transition

phosph

Example 19.
 Example 19.
 Example 19.
 Example 19.
 Example 19. Among the standard and phosphides metallies, sulfides, and phosphides are considered as doping phosphor atoms into indicating that this strategy is selenides, and phosphides^{tron}. Transition metal phos-

indicating that this strategy is conductive transition

phildes are considered as doping phosphor at combinition metal phosphides and hepondiates and phosphides are 2. (10), 2214005 (2 of 9)

doping, due to the electron-deficient d orbitals of Ru,

indicating that this strategy is conductive transition

metal phosphides and beyond.
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dicating that this strategy is conductive transition

tatal phosphides and beyond.
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All reagents we 28(10), 2214005 (2 of 9)

doping, due to the electron-deficient d orbitals of Ru,

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metal phosphides and beyond.
 2. Experimental Section
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doping, due to the electron-deficient d orbitals of Ru,

indicating that this strategy is conductive transition

metal phosphides and beyond.
 2.1 Materials

All reagents were used as received 28(10), 2214005 (2 of 9)

doping, due to the electron-deficient d orbitals of Ru,

indicating that this strategy is conductive transition

metal phosphides and beyond.
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All reagents were used as received 28(10), 2214005 (2 of 9)

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metal phosphides and beyond.
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doping, due to the electron-deficient d orbitals of Ru,

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metal phosphides and beyond.
 2.1 Materials

All reagents were used as received 2.28(10), 2214005 (2 of 9)

doping, due to the electron-deficient d orbitals of Ru,

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metal phosphides and beyond.
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All reagents were used as receive doping, due to the electron-deficient d orbitals of Ru,
indicating that this strategy is conductive transition
metal phosphides and beyond.
2. Experimental Section
2.1 Materials
All reagents were used as received with doping, due to the electron-deficient d orbitals of Ru,
indicating that this strategy is conductive transition
metal phosphides and beyond.
2. Experimental Section
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All reagents were used as received with The state is strategy is conductive transition
phosphides and beyond.
Xxperimental Section
Materials
reagents were used as received without further
cation. Ruthenium trichloride (RuCl₃, 99%), po-
m hydroxide (KOH, 9 metal phosphides and beyond.

2.1 Materials

All reagents were used as received without further

purification. Ruthenium trichloride (RuCl₃, 99%), po-

tassium hydroxide (KOH, 95%), absolute ethanol

(C₂H₃OH, 99%), **Experimental Section**
 1 Materials

All reagents were used as received without further

rification. Ruthenium trichloride (RuCl₃, 99%), po-

sium hydroxide (KOH, 95%), absolute ethanol

₂H₂OH, 99%), sodium hydrox **2.1 Materials**

All reagents were used as received without further

purification. Ruthenium trichloride (RuCl₃, 99%), po-

tassium hydroxide (KOH, 95%), absolute ethanol

(C₂H₃OH, 99%), sodium hydroxide (NaOH, 97%) All reagents were used as received without further
purification. Ruthenium trichloride (RuCl₃, 99%), po-
tassium hydroxide (KOH, 95%), absolute ethanol
(C₂H₃OH, 99%), sodium hydroxide (NaOH, 97%),
sodium hypophosphi purification. Ruthenium trichloride (RuCl₃, 99%), po-
tassium hydroxide (KOH, 95%), absolute ethanol
(C₂H₃OH, 99%), sodium hydroxide (NaOH, 97%),
sodium hypophosphite (NaH₂PO₂, 98%), ammonium
persulphate ((NH₄ tassium hydroxide (KOH, 95%), absolute ethanol

(C₂H₃OH, 99%), sodium hydroxide (NaOH, 97%),

sodium hypophosphite (NaH₂PO₂, 98%), ammonium

persulphate ((NH₄).S₂O₈, 98%), and hydrochloric acid

(HCl, 37%) w

phosphide (Cu,P) is considered as an ideal material

co. Copper foam (10 cm × 10 cm) was purchased from

derivative HER (Suzhou Kesheng and Metal Materials Company Lim-

or development of low-ock and highly active HER

d. for development of low-cost and highly active HER

starbou Kesheng and Metal Materials Company Lim-

catalyst, and its catalytic activity is strongly depen-

ited. Deionized water (DI, 18.2 MΩ · cm) was used in

Eduction erallyst, and its catalytic activity is strongly depen-

eral. Deionized water (Dl, 18.2 M Ω com) was used in

dent on the morphology and electronic structures¹⁶⁴. all experiments.

For example, Jiang and colleagues¹ dent on the morphology and electronic structures¹⁶⁹. all experiments.
For example, Jiang and colleagues^[17] preparad porous
 2.2 Preparations of Ru-Cu₃P/CF an

anoshests of N, P co-doped carbon wrapped Cu₂P.

wh electronic structures^[16]. all experiments.

all experiments.

12.2 **Preparations of Ru-Cu₃P/CF and Con-**

activity and long-term

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activity and l For example, Jiang and colleagues^[13] prepared porous

2.2 **Preparations of Ru-Cu₃P/CF and Con-**

manchects of N, P co-doped cataby warpled Cu₃P,

which shows high catalytic activity and long-term

scaling of HER bo nanosheets of N, P co-doped canbon wrapped Cu₁P,
whist have shigh catalytic exiting and long-term
stability of HFR both in KOH and H₂SO₁ solutions.
The principly coper found to its emptitting and H₂SO₁ solutions which shows high catalytic activity and long-term

scability of HER both in KOH and H:SO, solutions.

Solution is KOH and H:SO, solutions solutions squared ally they

Sure tal.¹⁹³ sylves interime phosphorization reasonstability of HFR both in KOH and H₂SO₃ solutions.

Typically, copper foum (CF) was firstly elcance by

Sun et al.¹¹⁶ synthesized the sell:Supported Cu₁P namo-

wire arranys by low temperature phosphorization reac-Sun et al.¹⁹³ synthesized the self-supported Cu₃P nano-
virtue arrays by low temperature phosphorization rease-
virtue and wheter second times to remove the surface
tion, which needs an overpetutial of 143 mV (vs.
imp (C₂H₃OH, 99%), sodium hydroxide (NaOH, 97%), sodium hypophosphite (NaH₂PO₂, 98%), ammonium persulphate ((NH₄)₂S₂O₈, 98%), and hydrochloric acid (HCl, 37%) were purchased from Energy Chemical Co. Copper foa sodium hypophosphite (NaH₂PO₂, 98%), ammonium
persulphate ((NH₄)₂S₂O₈, 98%), and hydrochloric acid
(HCl, 37%) were purchased from Energy Chemical
Co. Copper foam (10 cm × 10 cm) was purchased from
Suzhou Keshe persulphate ((NH₄₎,S₂O₈, 98%), and hydrochloric acid
(HCl, 37%) were purchased from Energy Chemical
Co. Copper foam (10 cm × 10 cm) was purchased from
Suzhou Kesheng and Metal Materials Company Lim-
ited. Deionized (HCl, 37%) were purchased from Energy Chemical

Co. Copper foam (10 cm × 10 cm) was purchased from

Suzhou Kesheng and Metal Materials Company Lim-

ited. Deionized water (DI, 18.2 M Ω ·cm) was used in

all experiments.
 Co. Copper foam (10 cm × 10 cm) was purchased from
Suzhou Kesheng and Metal Materials Company Lim-
ited. Deionized water (DI, 18.2 M $\Omega \cdot$ cm) was used in
all experiments.
**2.2 Preparations of Ru-Cu₃P/CF and Con-
trastiv** Suzhou Kesheng and Metal Materials Company Limited. Deionized water (DI, 18.2 M Ω ·cm) was used in all experiments.
 2.2 Preparations of Ru-Cu₃P/CF and Contrastive Samples

2.2.1 Synthesis of Ru-Cu₃P/CF and Contras ited. Deionized water (DI, 18.2 M Ω · cm) was used in
all experiments.
2.2 **Preparations of Ru-Cu₃P/CF and Con-**
trastive **Samples**
2.2.1 Synthesis of Ru-Cu₃P/CF
Typically, copper foam (CF) was firstly cleaned by
so all experiments.

2.2 Preparations of Ru-Cu₃P/CF and Con-

trastive Samples

2.2.1 Synthesis of Ru-Cu₃P/CF

Typically, copper foam (CF) was firstly cleaned by

sonication sequentially in hydrochloric acid (1 mol·L¹
 2.2 **Preparations of Ru-Cu₃P/CF and Contrastive Samples**
2.2.1 Synthesis of Ru-Cu₃P/CF
Typically, copper foam (CF) was firstly cleaned by
sonication sequentially in hydrochloric acid (1 mol·L⁺
HCl) and water several **trastive Samples**
2.2.1 Synthesis of Ru-Cu₃P/CF
Typically, copper foam (CF) was firstly cleaned by
sonication sequentially in hydrochloric acid (1 mol·L¹
HCl) and water several times to remove the surface
impurities 2.2.1 Synthesis of Ru-Cu₃P/CF
Typically, copper foam (CF) was firstly cleaned by
sonication sequentially in hydrochloric acid (1 mol·L⁺
HCl) and water several times to remove the surface
impurities or oxides. The clea Typically, copper foam (CF) was firstly cleaned by
nication sequentially in hydrochloric acid (1 mol·L¹
Cl) and water several times to remove the surface
purities or oxides. The cleaned CF (1 cm × 1 cm)
is instantly imm sonication sequentially in hydrochloric acid (1 mol·L¹
HCl) and water several times to remove the surface
impurities or oxides. The cleaned CF (1 cm × 1 cm)
was instantly immersed into a 10 mL aqueous solu-
tion contain HCl) and water several times to remove the surface
impurities or oxides. The cleaned CF (1 cm × 1 cm)
was instantly immersed into a 10 mL aqueous solu-
tion containing 1 mmol RuCl₃ at room temperature
for 2 min to obtai impurities or oxides. The cleaned CF (1 cm × 1 cm)
was instantly immersed into a 10 mL aqueous solu-
tion containing 1 mmol RuCl₃ at room temperature
for 2 min to obtain Ru-CF. 0.3 g NaH₂PO₂ and Ru-CF
were put at tw was instantly immersed into a 10 mL aqueous solution containing 1 mmol RuCl₃ at room temperature
for 2 min to obtain Ru-CF. 0.3 g NaH₂PO₂ and Ru-CF
were put at two adjacent porcelain boats, at the up-
stream and dow tion containing 1 mmol RuCl₃ at room temperature
for 2 min to obtain Ru-CF. 0.3 g NaH₂PO₂ and Ru-CF
were put at two adjacent porcelain boats, at the up-
stream and downstream of tube furnace, respectively.
The molar for 2 min to obtain Ru-CF. 0.3 g NaH₂PO₂ and Ru-CF
were put at two adjacent porcelain boats, at the up-
stream and downstream of tube furnace, respectively.
The molar ratio of P to Cu was 6:1. Subsequently, the
temper were put at two adjacent porcelain boats, at the up-
stream and downstream of tube furnace, respectively.
The molar ratio of P to Cu was 6:1. Subsequently, the
temperature of the tube furnace was elevated to 350
°C with a

CF.

⁴¹ (*LE Electrochem.*) 2022, 28(10), 2214005 (3 of 9)

alyst also was prepared by growing Cu(OH)₂ on clean

CF first, soaked in RuCl₃ for 2 min and then phospho-

mol ·L³ KOH aqueous s

rated. The derived sample

49. $#2\neq$ (*L Eletrochem.* > 2022, 28(10), 2214005 (3 of 9)

xlyst also was prepared by growing Cu(OH), on clean

correctrist, soaked in RuCl₃, for 2 min and then phospho-

and 1.² KOH aqueous solution, and the c $+ \frac{1}{2}$ ($+ \frac{1}{2}$ $+ \frac{1}{2}$ alyst also was prepared by growing Cu(OH), on clean

were performed at room temperature (25 °C) in 1.0

CF first, soaked in RuCl, for 2 min and then phospho-

mol -L¹ KOH aqueous solution, and the current den-

ractical alyst also was prepared by growing Cu(OH), on clean

CF first, scaked in RuCl, for 2 min and then phospho-

and then phospherical The derived sample is denoted as Ru-Cu₍p₂₋₃) sity was normalized by the generatic area CF first, soaked in RuCl, for 2 min and then phosphone in the L⁺ KOH aqueous solution, and the current defined. The derived sample is denoted as Ru-Cu_b-3/ silve electrocatallytic performance of commercial CC-
CF.
Cont rated. The derived sample is denoted as Ru-Cu_bP-3/sity was normalized by the geometric are

CF.

Contrastive sample without Ru-doping was pre-

celectrocatalytic performance of cond

magnetal performance of conditative vanced, German) test was performed using a Cu K_n

Then, the 12-µL ink was dropped on the radiation source. X-ray photoelectron spectroscopic and the resulting sample is recorded as

(XPS) measurements were performed on

was studied in 1.0 mol - L¹ KOH (pH = 14) solution The Cu(OH)₂CF was prepared by growth of Cu(OH)₂

by linear scanning voltamentery (LSV) with a sear-- on clean Cu foam directly, while the Ru-Cu(OH)²CF

ning range X-tool X-ray photoelectron spectrometer using Al as

The impacts of the Cu(OH);

the exciting source. Scanning electron microscopic

sition were explored. The Cu₅

(SEM) images were recorded by using a Zeiss Supra

tain 55. The hydrogen generation was evaluated by gas

deposition of Ru. The Ru-Cu_bP-1/CF catalyst was

chromatography (GC) (HuaAi GC-9560).
 2.4 Electrochemical Tests
 Example in Rull (600E determined state proposed by a chromatography (GC) (HuaAi GC-9560).
 Prepared by soaking CF directly in RuCl₃ solution
 EAL Electrochemical Tests
 **EVA Electrochemical are scanning reaction and followed by phos-

EVA Electrochemical impedance ar 2.4 Electrochemical Tests** for galvanic exchange reaction and followed by phos-

All the cletrochemical experiments were per-

formed with a CHI 660F electrochemical analyzer in paravoires precursor. To prepare the Ru-Cu All the electrochemical experiments were per-
from without the procedure of growing Cu(OH₎
form a vertice of electrochemical analyzar in nanowires precursor. To prepare the Ru-Cu_{(P-2}C/F
a typical three-electrochemical formed with a CHI 660E electrochemical analyzer in

a typical three-electrode setup. Recally, CF or con-

ratistive sample served as the working electrode, whilst deposition, then followed by Revult for Ru

a typical thre

 $\text{H}/\text{H}^{\#}(J. \text{Electrochem.})$ 2022, 28(10), 2214005 (3 of 9)
alyst also was prepared by growing Cu(OH)₂ on clean were performed at room temperature (25 °C) in 1.0
CF first, soaked in RuCl₃ for 2 min and then phospho-
mol $\#E\#$ (*I. Electrochem.*) 2022, 28(10), 2214005 (3 of 9)
alyst also was prepared by growing Cu(OH)₂ on clean
CF first, soaked in RuCl₃ for 2 min and then phospho-
mol·L⁻¹ KOH aqueous solution, and the current den- $# \ell \neq (J. Electrochem.)$

Elyst also was prepared by growing Cu(OH)₂ on clean

CF first, soaked in RuCl₃ for 2 min and then phosphonometric area of the current den-

rated. The derived sample is denoted as Ru-Cu₃P-3/

CF $28(10)$, 2214005 (3 of 9)
were performed at room temperature (25 °C) in 1.0
mol·L⁻¹ KOH aqueous solution, and the current den-
sity was normalized by the geometric area of the
electrode.
The electrocatalytic performa mol \cdot L⁻¹ KOH aqueous solution, and the current den- $2214005 (3 of 9)$
erformed at room temperature (25 °C) in 1.0
⁻¹ KOH aqueous solution, and the current den-
as normalized by the geometric area of the
de.
electrocatalytic performance of commercial
vas obtained by the fol $28(10)$, 2214005 (3 of 9)
were performed at room temperature (25 °C) in 1.0
mol·L⁻¹ KOH aqueous solution, and the current den-
sity was normalized by the geometric area of the
electrode.
The electrocatalytic performa electrode. 电化学(*J. Electrochem.*) 2022, 28(10), 2214005 (3 of 9)

ing Cu(OH)₂ on clean were performed at room temperature (25 °C) in 1.0

inin and then phospho-

mol·L⁻¹ KOH aqueous solution, and the current den-

enoted as Ru-

 $\mathbb{R} \times \mathbb{R}$
 $\mathbb{R} \times \mathbb{R}$ (*Electrochem.*) 2022, 28(10), 2214005 (3 of 9)

statiso was prepared by growing Cu(OH)₂ on clean

first, soaked in RuCl₃ for 2 min and then phosphometric area from the extended.

T dyst also was prepared by growing Cu(OH), on clean

alyst also was prepared by growing Cu(OH), on clean

were performed at room temperature (25 °C) in 1.0

CF first, soaked in RuCl, for 2 min and then phospho-

mol·L¹ (E/E_{CU} Electrochem.) 2022, 28(10), 2214005 (3 of 9)

alyst also was prepared by growing Cu(OH)₂ on clean

CF first, soaked in RuCl₃ for 2 min and then phospho-

mol·L¹ KOH aqueous solution, and the current den-
 H($t\frac{cos}{2}(L \text{ Klectrochem})$ 2022, 28(10), 2214005 (3 of 9)

alyst also was prepared by growing Cu(OH), on clean were performed at room temperature (25 °C) in 1.0

CF first, soaked in RuCl, for 2 min and then phospho-

mol -L¹ **EVALUATION THE THE SET AD-**
 EVALUATION THE SET AD-
 EVALUATION STATE SONG AD-1900 STATE SIGNATION OF THE SET AD-

First, soaked in RuCl, for 2 min and then phosphonomeric are performed at room temperature (25 °C) in then the test was performed using Cu(OH), on clean were performed at room temperature (25 °C) in 1.0

CF first, soaked in RuCl₁ for 2 min and then phosphone mole -L⁻¹ KOH aqueous solution, and the current den-

rate **EXALLACE THE CONDUM (FORTER CONDUM ASSES)**
 H(E#P(*LEIGENG)* and then phosphonometric (25 °C) in 1.0

CF first, soaked in RuCl₃ for 2 min and then phosphonometric are performed at room temperature (25 °C) in 1.0

CF $\frac{16}{2}\%$ *CLE LE LE CLE CLE CLE* **CLE CLE CLE** (10), 2214005 (3 of 9)

re performed at room temperature (25 °C) in 1.0
 $1 \cdot L^{-1}$ KOH aqueous solution, and the current den-

v was normalized by the geometric area of the

ctrode.

The electrocatalytic performance of co 28(10), 2214005 (3 of 9)
were performed at room temperature (25 °C) in 1.0
mol·L⁻¹ KOH aqueous solution, and the current den-
sity was normalized by the geometric area of the
electrode.
The electrocatalytic performance 28(10), 2214005 (3 of 9)
were performed at room temperature (25 °C) in 1.0
mol·L⁻¹ KOH aqueous solution, and the current den-
sity was normalized by the geometric area of the
electrode.
The electrocatalytic performance 28(10), 2214005 (3 of 9)
were performed at room temperature (25 °C) in 1.0
mol·L⁻¹ KOH aqueous solution, and the current den-
sity was normalized by the geometric area of the
electrode.
The electrocatalytic performance 28(10), 2214005 (3 of 9)
were performed at room temperature (25 °C) in 1.0
mol·L¹ KOH aqueous solution, and the current den-
sity was normalized by the geometric area of the
electrode.
The electrocatalytic performance o 28(10), 2214005 (3 of 9)
were performed at room temperature (25 °C) in 1.0
mol·L¹ KOH aqueous solution, and the current den-
sity was normalized by the geometric area of the
electrode.
The electrocatalytic performance o (25 °C) in 1.0

e current den-

ic area of the

of commercial

rocedure. Two

were added to
 $1 (V:V = 1:1)$,

ution and son-

⁻¹ catalyst ink.

he cleaned CF,

Pt/CF. 28(10), 2214005 (3 of 9)
were performed at room temperature (25 °C) in 1.0
mol·L¹ KOH aqueous solution, and the current den-
sity was normalized by the geometric area of the
electrode.
The electrocatalytic performance o 28(10), 2214005 (3 of 9)
were performed at room temperature (25 °C) in 1.0
mol·L¹ KOH aqueous solution, and the current den-
sity was normalized by the geometric area of the
electrode.
The electrocatalytic performance o 28(10), 2214005 (3 of 9)
were performed at room temperature (25 °C) in 1.0
mol·L¹ KOH aqueous solution, and the current den-
sity was normalized by the geometric area of the
electrode.
The electrocatalytic performance o (10), 2214005 (3 of 9)

ore performed at room temperature (25 °C) in 1.0

ol¹-L⁻¹ KOH aqueous solution, and the current den-

y was normalized by the geometric area of the

ctrode.

The electrocatalytic performance of 28(10), 2214005 (3 of 9)
were performed at room temperature (25 °C) in 1.0
mol·L¹ KOH aqueous solution, and the current den-
sity was normalized by the geometric area of the
electrode.
The electrocatalytic performance o were performed at room temperature (25 °C) in 1.0
mol·L¹ KOH aqueous solution, and the current den-
sity was normalized by the geometric area of the
electrode.
The electrocatalytic performance of commercial
Pt/C was obt were performed at room temperature (25 °C) in 1.0
mol·L¹ KOH aqueous solution, and the current den-
sity was normalized by the geometric area of the
electrode.
The electrocatalytic performance of commercial
Pt/C was obt

Contrastive sample without Ru-doping was pre-

Contrastive sample without Ru-doping was pre-

The electroceatalytic performance of commercial

ed by following the same procedure, directly

PFC was obtained by the followin Contrastive sample without Ru-doping was pre-

predectoreal by following the same procedure, directly PrC was obtained by the following procedure. Two

phosphoraing Cu(OH):/CF without soaking in RuCL

analyzer militagrams pared by following the same procedure, directly

PDC was obtained by the following procedure. Two

phosphorating Cu(OH)_C/CF windot scaling in RuCl₃ milligrams of commercial PUC powerle were added to

solution. The obt phosphorating Cu(OH)₇CF without soaking in RuCl₃ milligrams of commercial PtC powder were added to

solution. The obtained sample is named Cu₁P/CF. an initure of 400 mL vater and ethnen (*V*: 19 = 1: 1),
 2.3 Chara solution. The obtained sample is named Cu_jP/CF. an inixture of 400 mL water and ethanol ($V:V = 1:1$),
 2.3 Characterizations
 2.2 Characterizations
 2.2 Characterizations
 2.2 Characterizations
 2.2 C 2.3. Characterizations
 Electrode and Source And Form CNRD, Bruker D8 Ad- Fourth of the Barge 1² coality interactions of the cannot CFRD and the resulting sample is recorded by the cannot CFR and respectively.

Area Powder X-ray diffraction (XRD, Bruker D8 Ad-

icated for 30 min to make a 5 mg -L¹ catalyst ink.

Itation source. X-ray photoclectron spectroscopic and the resulting sample is recorded as PiCF.

Itation source. X-ray ph is performed using a Cu K_n

Then, the 12-µL ink was dropped on the cleaned CF,

hotoelectron spectroscopic and the resulting sample is recorded as Pt/CF.

in the performed on a PHI **3 Results and Discussion**

in spectro radiation source. X-ray photoelectron spectroscopic and the resulting sample is recorded as PtCF.

(XPS) measurements were performed on a PHI **3 Results and Discussion**

X-tool X-ray photoelectron spectrometer using Al as (XPS) measurements were performed on a PHI **3 Results and Discussion**

X-tool X-ray photoelectom spectrometer using Al as

The imagests of the Cu(OH)₂ growth and Ru depo-

the exciting source. Scanning electron microsco is the Cu_(OH), growth and Ru deposites the Cu(OH), growth and Ru deposites conce Scanning electron microscopic sition were explored. The Cu_HP/CF catalyst was obtained mere recorded by using a Zeias Supprais dianed by mol·L[.] KOH aqueous solution, and the current density was normalized by the geometric area of the electrocate.
The electrocatalytic performance of commercial Pt/C was obtained by the following procedure. Two milligrams o sity was normalized by the geometric area of the
electrode.
The electrocatalytic performance of commercial
PiVC was obtained by the following procedure. Two
milligrams of commercial PVC powed were aded to
a mixture of 400 The electrocatalytic performance of commercial
Pt/C was obtained by the following procedure. Two
milligrams of commercial Pt/C powder were added to
a mixture of 400 mL water and ethanol ($V:V = 1:1$),
followed by 40 μ L Pt/C was obtained by the following procedure. Two
milligrams of commercial Pt/C powder were added to
a mixture of 400 mL water and ethanol ($V:V = 1:1$),
followed by 40 μ L of 5wt% Nafion solution and son-
icated for 30 milligrams of commercial Pt/C powder were added to
a mixture of 400 mL water and ethanol ($V:V = 1:1$),
followed by 40 μ L of $5wt\%$ Nafion solution and son-
icated for 30 min to make a 5 mg·L¹ catalyst ink.
Then, the a mixture of 400 mL water and ethanol $(V:V = 1:1)$,
followed by 40 μ L of $5wt\%$ Nafion solution and son-
icated for 30 min to make a 5 mg · L⁺ catalyst ink.
Then, the 12- μ L ink was dropped on the cleaned CF,
and t lowed by 40 μ L of 5wt% Nafion solution and son-
ted for 30 min to make a 5 mg · L⁻¹ catalyst ink.
en, the 12- μ L ink was dropped on the cleaned CF,
d the resulting sample is recorded as Pt/CF.
Results and Discussi icated for 30 min to make a 5 mg $\cdot L^{-1}$ catalyst ink.

Then, the 12- μL ink was dropped on the cleaned CF,

and the resulting sample is recorded as Pt/CF.
 3 Results and Discussion

The impacts of the Cu(OH)₂ grow Then, the 12- μ L ink was dropped on the cleaned CF,
and the resulting sample is recorded as Pt/CF.
3 Results and Discussion
The impacts of the Cu(OH)₂ growth and Ru depo-
sition were explored. The Cu₃P/CF catalyst and the resulting sample is recorded as Pt/CF.
 3 Results and Discussion

The impacts of the Cu(OH)₂ growth and Ru deposition were explored. The Cu₃P/CF catalyst was obtained by directly phosphorating Cu(OH)₂/CF w **3 Results and Discussion**
The impacts of the Cu(OH)₂ growth and Ru deposition were explored. The Cu₃P/CF catalyst was obtained by directly phosphorating Cu(OH)₂/CF without deposition of Ru. The Ru-Cu₃P-1/CF catal The impacts of the Cu(OH)₂ growth and Ru deposition were explored. The Cu₃P/CF catalyst was obtained by directly phosphorating Cu(OH)₂/CF without deposition of Ru. The Ru-Cu₃P-1/CF catalyst was prepared by soaking

the exciting source, Scanning electron microscopic

Sion were explored. The Cu_iP/CF catalyst was ob-

S5. The hydrogen generation was evaluated by gas

S5. The hydrogen generation was evaluated by gas

deposition of Ru. (SEM) images were recorded by using a Zeias Supra

tained by directly phosphorating Cu(OH)₂CF without

55. The hydrogen generation was evaluated by gas

echromatography (GC) (HuaAi GC-9560).
 2.4 Electrochemical Tests sition were explored. The Cu_BP/CF catalyst was obtained by directly phosphorating Cu(OH)₂/CF without deposition of Ru. The Ru-Cu_BP-1/CF catalyst was prepared by soaking CF directly in RuCl₃ solution for galvanic e tained by directly phosphorating Cu(OH)₂/CF without
deposition of Ru. The Ru-Cu₃P-1/CF catalyst was
prepared by soaking CF directly in RuCl₃ solution
for galvanic exchange reaction and followed by phos-
phorization deposition of Ru. The Ru-Cu₃P-1/CF catalyst was
prepared by soaking CF directly in RuCl₃ solution
for galvanic exchange reaction and followed by phos-
phorization without the procedure of growing Cu(OH)₂
nanowires p prepared by soaking CF directly in RuCl₃ solution
for galvanic exchange reaction and followed by phos-
phorization without the procedure of growing Cu(OH)₂
nanowires precursor. To prepare the Ru-Cu₃P-2/CF
catalyst, for galvanic exchange reaction and followed by phos-
phorization without the procedure of growing Cu(OH)₂
nanowires precursor. To prepare the Ru-Cu₃P-2/CF
catalyst, CF was soaked in RuCl₃ solution for Ru
deposition, orization without the procedure of growing Cu(OH)₂
nowires precursor. To prepare the Ru-Cu₃P-2/CF
alyst, CF was soaked in RuCl₃ solution for Ru
position, then followed by growth of Cu(OH)₂ rano-
ays and phosphoriz nanowires precursor. To prepare the Ru-Cu₃P-2/CF
catalyst, CF was soaked in RuCl₃ solution for Ru
deposition, then followed by growth of Cu(OH)₂ nano-
arrays and phosphorization.
The Cu(OH)₂/CF and Ru-Cu(OH)₂/CF

 $\# \# \# (L \n *Electrochem.*) 2022, 28(10), 2214005 (4 of 9)$ Ru-Cu₃P-3/CF. After phosphorization, the diffraction CF, which shares the direct growth of Cu(OH)₂ nano-

peaks for Cu(OH)₂ disappeared and the characteristic array $# \ell \# (J. Electrochem.) 2022, 28(10), 2214005 (4 of 9)$ Ru-Cu₃P-3/CF. After phosphorization, the diffraction CF, which shares the direct growth of Cu(OH)₂ mano-

peaks for Cu(OH)₂ disappeared and the characteristic arrays on CF, the (112), $\frac{1}{2}$ (*Electrochem.*) 2022, 28(10), 2214005 (4 of 9)

Ru-Cu₃P-3/CF. After phosphorization, the diffraction

cF, which shares the direct growth of Cu(OH)₂ nano-

peaks for Cu(OH)₂ disappeared and the $\frac{\frac{1}{2} \mathcal{L}^{\#}(L \text{ *Electrochem.*}) 2022, 28(10), 2214005 (4 of 9)}{\text{Ru-Cu}_3\text{P-3/CF.}}$ Ru-Cu₃P-3/CF. After phosphorization, the diffraction

cr, which shares the direct growth of Cu(OH)₂ nano-

peaks for Cu(OH)₂ disappea $H_2E\cong (J. Electron) 2022, 28(10), 2214005 (4 of 9)$
Ru-Cu₃P-3/CF. After phosphorization, the diffraction CF, which shares the direct growth of Cu(OH)₂ nano-
peaks for Cu(OH)₂ disappeared and the characteristic arrays on CF, a **EVALUATION EXECT ADMOND THE CUSP/CF.** And the diffraction (F, which shares the direct growth of Cu(OH), nano-

peaks for Cu(OH), disappeared and the characteristic arrays on CF, and results in the high coverage of

refle $Ru-Cu₃P-3/$

28(10), 2214005 (4 of 9)
CF, which shares the direct growth of Cu(OH)₂ nano-
arrays on CF, and results in the high coverage of
Cu₃P on Cu foam^[15]. Since the loading of Ru was quite
low, no characteristic peak of ru 28(10), 2214005 (4 of 9)

CF, which shares the direct growth of Cu(OH)₂ nano-

arrays on CF, and results in the high coverage of

Cu₃P on Cu foam^[15]. Since the loading of Ru was quite

low, no characteristic peak o 28(10), 2214005 (4 of 9)

CF, which shares the direct growth of Cu(OH)₂ nano-

arrays on CF, and results in the high coverage of

Cu₃P on Cu foam^[15]. Since the loading of Ru was quite

low, no characteristic peak o 28(10), 2214005 (4 of 9)

CF, which shares the direct growth of Cu(OH)₂ nano-

arrays on CF, and results in the high coverage of

Cu₃P on Cu foam^[15]. Since the loading of Ru was quite

low, no characteristic peak o 28(10), 2214005 (4 of 9)

CF, which shares the direct growth of Cu(OH)₂ nano-

arrays on CF, and results in the high coverage of

Cu₃P on Cu foam^[15]. Since the loading of Ru was quite

low, no characteristic peak o $\frac{3(10)}{2}$, 2214005 (4 of 9)
 $\frac{1}{2}$, which shares the direct growth of Cu(OH)₂ nano-
 $\frac{1}{2}$, which shares the direct growth of Cu(OH)₂ nano-
 $\frac{1}{2}$, on Cu foam^[15]. Since the loading of Ru was quite
 28(10), 2214005 (4 of 9)

CF, which shares the direct growth of Cu(OH)₂ nano-

arrays on CF, and results in the high coverage of

Cu₃P on Cu foam^[15]. Since the loading of Ru was quite

low, no characteristic peak o 电化学(*J. Electrochem.*) 2022, 28(10), 2214005 (4 of 9)

zation, the diffraction CF, which shares the direct growth of Cu(OH)₂ nano-

and the characteristic arrays on CF, and results in the high coverage of

and (113) pl

 $# \&L^{\#}(J. \nElectrochem.) 2022, 28(10), 2214005 (5 \text{ of } 9)$

spectrum of Cu 2p for Ru-Cu₃P-3/CF, where the CF, which displays Cu₃P nanoparticles (Figure 4c and

peaks at 932.9 and 952.4 eV are indexed to the Cu¹⁺ 4d), poss $\text{H}(k\#(J. \text{Electrochem.}) 2022, 28(10), 2214005 (5 \text{ of } 9)$

spectrum of Cu 2p for Ru-Cu₃P-3/CF, where the CF, which displays Cu₃P nanoparticles (Figure 4c and

peaks at 932.9 and 952.4 eV are indexed to the Cu¹⁺

2p_{2x} a $\text{#}\{\&\cong (J. \text{Electrochem.}) \text{ } 2022, 28(10), 2214005 \text{ (}5 \text{ of } 9\text{)}\}$

spectrum of Cu 2p for Ru-Cu₃P-3/CF, where the CF, which displays Cu₃P nanoparticles (Figure 4c

peaks at 932.9 and 952.4 eV are indexed to the Cu¹

in Figure 3b, and the two peaks were observed at

4H4.3 and 461.9 eV(18), which are assigned to Ru (bilowed by phosphorization, which results in rougher

4H₂, and 3*P₃₂* o⁷RuP₂, respectively^{[37}]. Figure 3c s 484.3 and 461.9 cV¹³⁶), which are assigned to Ru followed by phosphorization, which results in rougher $2p_{10}$ and $2p_{10}$ follows $2p_{10}$ and $2p_{10}$ for faller $2p_{10}$ for $2p_{10}$. The signed $2p_{10}$ resulted $3\rho_{1/3}$ and $3\rho_{1/3}$ of RuP₃, respectively^[37]. Figure 3c shows surface, as shown in Figure 4d, and may provide large-
the high resolution XPS spectrum of P 2p for er surface area. Element mapping images (Figure the high resolution XPS spectrum of P $2p$ for cr surface area. Element mapping images (Figure Ru-Cu3-3/CF, where the peak at 134.3 eV was ss-

SEC-U3-3/CF, where the peak at 130.3 eV was ss-

SEC-U3-3/CF, when the surfac

 $k \neq (J. Electrochem.) 2022, 28(10), 2214005 (5 of 9)$
 $-3/CF$, where the CF, which displays Cu₃P nanoparticles (Figure 4c and

ndexed to the Cu¹⁺ 4d), possibly due to the disordered collapse of nano-

¹⁰, while the peaks arrays ⁴¹ 48% (*J. Electrochem.*) 2022, 28(10), 2214005 (5 of 9)

spectrum of Cu 2p for Ru-Cu₃P-3/CF, where the CF, which displays Cu₃P nanoparticles (Figure 4c and

peaks at 932.9 and 952.4 eV are indexed to the Cu¹⁺ . Figure 3b, and the peaks were observed at the high resolution XPS spectrum of Ω_{2} is shown in Figure 3, and 451.9 is shown because the cution XPS spectrum of Ru 3p is shown because $2p_{3/2}$ and $2p_{1/2}$, respectiv **in Figure 3b**, and 960.9 cV and 96.9 cV and the two peaks at 93.2 and 97.2 and 97.9 and 97.2 and 97.9 and 97.2 and 97.2 and 97.2 and 97.2 \pm (*k*) \pm ²(*L Electrochem.*) 2022, 28(10), 2214005 (5 of 9)
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at 9 $2\rho_{18}$ and $2\rho_{18}$ respectively, in Cu₍D¹⁰⁸, while the peaks

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in Figure 3b, and the two peaks were observed at tained by soaking Cu(OH)₂/CF in RuC₁, 28(10), 2214005 (5 of 9)
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follo ure 4b) exhibited only textured surface due to the absence of Cu(OH)₂ nanoarrays. Ru-Cu₃P-3/CF was obtained by soaking Cu(OH)₂/CF in RuCl₃ solution and followed by phosphorization, which results in rougher surface sence of Cu(OH)₂ nanoarrays. Ru-Cu₃P-3/CF was obtained by soaking Cu(OH)₂/CF in RuCl₃ solution and followed by phosphorization, which results in rougher surface, as shown in Figure 4d, and may provide larger surfa tained by soaking Cu(OH)₂/CF in RuCl₃ solution and
followed by phosphorization, which results in rougher
surface, as shown in Figure 4d, and may provide larg-
er surface area. Element mapping images (Figure
S2d-g) dem 电化学(*J. Electrochem.*) 2022, 28(10), 2214005 (5 of 9)
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Ru and the uni surface, as shown in Figure 4d, and may provide larger
er surface area. Element mapping images (Figure
S2d-g) demonstrate the successful incorporation of
Ru and the uniform distribution of each element on
the samples, in a er surface area. Element mapping images (Figure S2d-g) demonstrate the successful incorporation of Ru and the uniform distribution of each element on the samples, in agreement with the XPS results. The doping level of Ru

 $\frac{d}{dt}\mathcal{L}^{\#}(J. \text{Electrochem.}) 2022, 28(10), 2214005 (6 of 9)$ doping of Ru into Cu₃P can maneuver the RDS from iss (Figure 5d). Distinctly, the Ret values were in the Volmer step on Cu₃P/CF to Heyrovsky step on iss (Figure $\mathbb{E}E^{\#}(J. Electron.)$ 2022, 28(10), 2214005 (6 of 9)
doping of Ru into Cu₃P can maneuver the RDS from
Volmer step on Cu₃P/CF to Heyrovsky step on order of Cu₃P/CF > Ru-Cu₃P-1/CF > Ru-Cu₃P-2/CF >
Ru-Cu₃P-3/CF^[23]

 $# \&L^{\#}(J. \nElectrochem.) 2022, 28(10), 2214005 (6 of 9)$ doping of Ru into Cu₃P can maneuver the RDS from

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Welmer step on Cu₃P/CF to Heyrovsky step on

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Volmer step on Cu₃P/CF to Heyrovsky step on order of Cu₃P/CF > R $\text{ft}\mathbb{R}^{\infty}$ (*L Electrochem.*) 2022, 28(10), 2214005 (6 of 9)

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 $# \& \# \langle J. \text{ *Electrochem.* } \rangle$ 2022, 28(10), 2214005 (7 of 9)

area (Figure 5e), and could be associated with its larger Detailed SEM images and CV curves of ECSA

current density^[18]. The ECSA-normalized LSV curves meas $# \& \# \langle I. \t{Electrochem.} \rangle 2022, 28(10), 2214005 (7 of 9)$ Farea (Figure 5e), and could be associated with its larger Detailed SEM images and CV curves of ECSA

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(Figure S4) indicate an over potential of 227 mV at a

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Current density¹⁸⁸. The ECSA normalized LSV curves measureme **Example 1988**
 Remarkably and CV curves of ECSA
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 37/CF (Figure 54), and could be associated with its larger Detailed SEM images and CV curves of ECSA

current density^[18]. The ECSA-normalized LSV curves **Example 19:** The match of CHC-Cu₃P-3/CF, after the angligible shift in the whole potential range.

Example of Nu-Cu₃P-3/CF, and the match of CHC-CU₃P-3/CF, and the state of Ru-Cu₃P-3/CF, and the state of Ru-Cu₃ 49. $\frac{1}{2}$ Electrochema, 2022, 28(10), 2214005 (7 of 9)

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current density⁶¹⁸. The ECSA-normalized LSV curves measu **H** (Eigenc 5c), and could be associated with its larger
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Citygic S4) indicate an over potential of 227 mV at a

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current density⁵¹⁰. The FCSA-normalized LSV curves monsurements.

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current density¹⁶. The ECSA-normalized 1SPM images and CV curves of ECSA

current density¹⁶. The ECSA-normalized 1SV curves

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urrea (Figure Sc), and could be associated with its larger Detailed SEM images and CV curves of ECSA

current density^{[68}. The ECSA-normalized LSV curves area (Figure 5e), and could be associated with its larger Detailed SFM images and CV curves of FCSA

current density³¹⁹. The FCSA-normalized LSV curves measurements.

(Figure S4) indicate an over potential of 227 mV at are (Pigure 26) and could be somedable which singure

are the RICA, anomalized LSV curves

Crigert S4) indicate an over potential of 227 mV at a

current density of 0.02 mA cm⁻ (ECSA, which is low-
 Exerce the main the current density^{om}. In EECSA anomalized LSV curves

(Figure S4) miciation and experimental of 227 mV at a

current density of 0.02 mA cm² (ECSA), which is low-

cert fram those of Ru-Cu_iP-2CF (268 mV), Ru-Cu_iP-1/ [For the Ru-Cu₂P-3P/CF maintained the move with the porous convertion.

The Ru-Cu3P-2CF (268 mV), Ru-Cu3P-1/ $\left\{\frac{1}{2}\right\}$ Experiment only and Cu3P/CF (332 mV), suggesting the
 $\frac{143}{148}$, the act dependent oxygen ev For excellent and the control in the sumple μ is the control in the sumple of the control in the sumpl Er (250 m/v) and conject (36 m/v), suggesting to the constrained by growth oxides[1]. J. Electrochem, 2022, 28(2): 139-

3/CF t than other catalysts. Figure 5f exhibits an ex-

cellent catalytic durability of Ru-Cu₂P-3/ EVIRTHEN matrix of Ru-Cu_BP-SYCF was mention μ and μ Sole of the CupP-3/CF and results and the phosphorization. The Ru-Gondling show and a negligible shift in the whole potential range.

Solo cycles, the polarization curve of Ru-CupP-3/CF after all station by the phosphoriz

4 Conclusions

Conclusion and the parameteric and the parameter and the electro-could significantly increase the polarization curve of Ru-CupP-3/CF and 2022, 2700: 1-14.

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4 Conclusions the proof of Concept is a current density of the Ru-CupP/CF catalyst with the process opper [5] Wang Z, Dn H T, Liaz **4 CORECOMISIONS**
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signals are the catalytic proportion of Cu(OH), n Iom substrate and excellent IER (performance was μ in X , X and X and synthesized by growth of Cu(OH), nanoarrays, dop-

ing of Ru and low temperature phosphorization. The

results showed that the phosphorization of Cu(OH),

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realising social values utilis showed that the phosphorization of Cu(OII).

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 nanoarrays could significantly increase the electro-

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sociated with its larger Detailed SEM images and CV curves of ECSA
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ECSA) which is low. **Peforonoge:**

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- 28(10), 2214005 (7 of 9)

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[1] Zhang L H, Chuai H Y, Liu H, Fan Q, Kuang S Y, Zhang

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Detailed SEM images and CV curves of ECSA

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泡沫铜支撑 Ru 掺杂 Cu、P 自支撑催化剂 及其析氢性能

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摘要: 过渡金属磷化物(TMP)是一种用于碱性条件下析氢反应(HER)的有效催化剂, 然而其活性严重受限于水 解离步。本文通过在泡沫铜(CF)上生长 Cu(OH),纳米阵列, RuCl3溶液浸泡和磷酸化, 制备了一种具有较大比表 面积和适当 Ru 掺杂的 Ru-Cu₃P 自支撑催化剂 (Ru-Cu₃P/CF)。作为一种优良的 HER 催化剂, 在电流密度为 10 my mesommatrix manusqup, val. vanoseminit, and the heritograp of order of the material of Conservation of the material of Cuse B.E. Fract-dependent account of the same proposed to the extropologic materially so the propos 性能的提高可以归因于 Ru 掺杂磷化铜促进水解离过程, 以及 Cu(OH), 纳米阵列衍生 Cu,P 纳米结构具有更高的 电化学活性面积, 从而保证了更多的活性位点。本论文突出了具有空的 d 轨道的金属掺杂促进水解离的重要性, 为高性能电解水析氢催化剂的设计提供了新思路。

关键词: 电催化:水解离: 析氢反应:磷化亚铜:钌掺杂