[Journal of Electrochemistry](https://jelectrochem.xmu.edu.cn/journal)

[Volume 28](https://jelectrochem.xmu.edu.cn/journal/vol28) | [Issue 8](https://jelectrochem.xmu.edu.cn/journal/vol28/iss8)

2022-08-28

Low-Crystallinity and Heterostructured AuPt-Ru@CNTs as Highly Efficient Multifunctional Electrocatalyst

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Recommended Citation

Tuan-Jie Gan, Jian-Ping Wu, Shi Liu, Wen-Jun Ou, Bin-Ling Bin-Ling, Xiong-Wu Kang. Low-Crystallinity and Heterostructured AuPt-Ru@CNTs as Highly Efficient Multifunctional Electrocatalyst[J]. Journal of Electrochemistry, 2022 , 28(8): 2201241. DOI: 10.13208/j.electrochem.2201241 Available at:<https://jelectrochem.xmu.edu.cn/journal/vol28/iss8/2>

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$\begin{array}{lll} &\text{\rm if}&\mathcal{H}\text{ &}\mathcal{G}^2\\ &\text{\rm if}&\mathcal{H}\text{ &}\mathcal{H}\text{ &$ Highly Efficient Multifunctional Electrocatalyst $\begin{array}{c} \# \quad \# \\ \hline \\ \textcolor{red}{ \# \quad } \textcolor{$ $\begin{tabular}{ll} $\quad \# \quad \mathcal{H} \ & \# \ \\ \hline \textit{J. Electrochem. 2022, 28(8), 2201241 (1 of 10)} \\\hline \textit{DOL: 10.13208/j.electrochem.220124} & \textit{Htp://electrochem.xml.edu.cn} \end{tabular} \label{eq:1}$ $\begin{tabular}{ll} {\bf{limit} y \ and \ Heterostructured \ AuPt-Ru@CNTs \ as} \\\hline \textit{J. 1 infty} & \textit{J. 2 infty} \\ \hline \end{tabular} \label{eq:1} {\bf{limit} y \ and \ Heterostructured$ $\begin{array}{ll} \hbox{\small $\#$} & \# & \# \\ \hbox{\small $\#$} & \# & \# \\ \hline 10.13208/j.electrochem.220124 & \text{http://electrochem.xml.edu.cn} \\ \hline \end{array}$ $\begin{array}{ll} \hline \end{array} \begin{minipage}{0.8cm} & \text{Htp://electrochem.xml.edu.cn} \\ \hline \end{minipage} \begin{minipage}{0.8cm} \begin{minipage}{0.8cm} \begin{minipage}{0.8cm} \begin{minipage}{0.8cm} \begin{minipage}{0.8cm} \begin{minipage}{0.8cm} \begin{minipage}{0$ と 学
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DOI: 10.13208f) electrochem, 220124
 **Low-Crystallinity and Heterostructured AuPt-Ru@CNTs as

Highly Efficient Multifunctional Electrocatalyst**

Tuan-Jie Gan¹, **18** *B. Riectrochem, 2022, 28(8), 220124* (1 of 10)

DOI: 10.13208/j.electrochem,220124 Hup://electrochem,xma.edu.cn
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J. Electrochem. 2022, 28(8), 2201241 (1 of 10)

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A so compared to the high cyalidinity AdPit alloy, AdPit alloy, Achieving the mass activit As compared to the high-prysullimity AuPt alloy, AuPt alloy in AuPt-Ru hetrestructure became amorphous, and AuPt-Ru showed
superfor consigly activity toward ellured horizolation reaction (TOR), achieving the mass ucivity superior eatalytis activity toward ethanol ocidation reaction (FGR), achieving the mass activity of Pt as high as 21.44 A - mg⁻ due
to the high tost-emulta cost must device high cost-effect. The intermediates species of to the high tolerance toward the poisoning species. The intermediates species of the LOR were also examined by to-sita ITR species
or towards to the conducts towards FOR was also excellent and the degradation in the activ xygen reduction reaction (ORR) and alcohol oxidation reaction,
volution reaction (OER) during water splitting. Preparing alloy
ivj of these catalysts from the perspective of strain effect, en-
exist AuPt alloy as a soild volution reaction (OER) during water splitting. Preparing alloy
rity of these catalysts from the perspective of strain effect, en-
osit AuPt alloy as a solid solution phase on amorphous Ru sup-
defined AuPt-Ru heterostruc rity of these catalysts from the perspective of strain effect, ensist AuPt alloy as a solid solution phase on amorphous Ru sup-
defined AuPt-Ru heterostructured catalysts were examined by
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inded AuP-Ru heterostructured catalysts were examined by
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u heterostructure became amorphous, and AuPt-Ru showed
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PUC and RuO₂ catalysts, as Either as: Gan The Cite as the Cite and Cite and the Cite and the Cite and the Cite and the Cite and Cite **Example 18** ($R_2 \stackrel{\text{def}}{=}$

Absorption 2022, 28(8), 2201241 (1 of 10)

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 Example 16.187.1 Fig. 10.1 Lui, Wen-Jun Ou², Bin-Ling² *L* Electrochem, 2022, 28(8), 2201241 (1 of 10)

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DOW-**Crystallinity and Heterostructured AuPt-Ru@CNTs as

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Tuan-Jie Gan¹, Jian-Ping Wu¹, Shi Liu³, Wen-Jun Ou², B DOI: 10.13208 \tilde{g} dectrochem.220124 Http://electrochem.xmu.edu.en
 LOW-Crystallinity and Heterostructured AuPt-Ru@CNTs as
 Highly Efficient Multifunctional Electrocatalyst

Tuan-Jie Gan¹, Jian-Ping Wu¹, Shi Li **Low-Crystallinity and Heterostructured AuPf-Ru@CNTs as

Highly Efficient Multifunctional Electrocatalyst

Tuan-Jic Garn, Jian-Ping Wu, Shi Liu², Wen-Jun Ou², Bin-Ling², Xiong-Wu Kang²⁺

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Tuan-Jie Gan¹, Jian-Ping Wu¹, Shi Liu², Wen-Jun Ou², Bin-Ling², Xiong-Wu Kang^{2*}

(*I. Jiangmen Poser Supply Bureau of Guangdong Pover Grid Co., Ltd, 152, Jian* Tuan-Jie Gan¹, Jian-Ping Wu¹, Shi Liu², Wen-Jun Ou², Bin-Ling², Xiong-Wu Kang²⁺
(*I. Isangmen Posser Supply Bureau of Guangdong Poteer Grid Co., <i>Ltd.*, 152, *Jianshe Second Road,*
Jiangmen 529030, Guangdong, Tuan-Jie Gan¹, Jian-Ping Wu¹, Shi Liu², Wen-Jun Ou², Bin-Ling², Xiong-Wu Kang²⁷
(1. *Jiangmen Poser Supply Bureau of Guanglong Poser Grid Co., Ltd. 152, Jianshe Second Road,
<i>Jiangmen 529030, Guanglong, China;* The stability of the stability of the catalysts of the stability of the catalysts are also excellent and the activity of the catalysts i (1. I diagnment Power Suppy P Dureau of Cuangdoong Power Grid Co., Ltd, 152, Jadames Sconta Road, μ , Ltd, Banne Sconta Road, Methuacum Street, Guangzhong Energy Technology Go, Ltd, 808 Dongfeng East Road, Methuacum Str Jumpuren 229030, Giumgtong, Chinna; 2. Giumgtong Hinthydrogen Energy Technology Co., 1td,

808 Dongfeng East Road, Meihuacun Street, Guangshou 527499, Guangshou, China)

Albstract: The catalytic entivity of the catalysts in Energy Technology Co., Ltd,

77499, Guangdong, China)

ucture of the catalysts, and the exploration of

are always at the central. Currently, platinum

reaction (ORR) and alcohol oxidation reaction,

(OER) during water 808 Dongfeng East Road, Meihuarun Street, Guangchou 527499, Guangchou, Ghina)
 Abstract: The catalytis activity of the catalyts is strongly dependent on the straiture of the catalyts, and the exploration of

their corre **Abstract:** The eatalytis activity of the eatalysts is strongly dependent on the structure of the eatalysts, and the exploration of their correlation and structure controlled tynthesis of the high-performance catalysts ar **Allottract:** The catalytic activity of the catalyts is strongly dependent on the stanctare of the catalyts, and the exploration of the high-performance catalytical methods are always at the expansion of the increments an

From the multicomponent heterostructures for the synthesis of high-performance and multifunctional electrocatalysts.
 Key words: rutherium; AuPt Alloy: heterostructure; chanol oxidation; hydrogen evolution; oxygen evolu

1 Introduction tional design and controlled synthesis of the high-per-

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ic water splitting, while ruthenium (Ru) and iridium (Ir) ides displaying a remarkable performance for OER in
based catalysts are recognized as the best catalysts for $\text{H}/\mathbb{Z}^{\#}(J. \text{Electrochem.})$ 2022, 28(8), 2201241 (2 of 10)

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interface engineering while ruthenium (Ru) and indium (Ir) ides displaying a remarkable performance for OER in

based catalysts are recognized as the best catalysts **in the catalytic state of the catalytic activity (** \mathbb{R}^n **) and** \mathbb{R}^n **) and** \mathbb{R}^n **and** \mathbb{R}^n **and \math**

Friedmot the catalytic certifical states. The interestant of the regulation mechanism are very immediate to the bifunctional mechanism^{19,10}, and the incorporation of Au into Pt catalysts can lead to profound en-
tion of able to the bifunctional mechanism¹⁰²¹, and the incorpora-

and the incorpora-

to the bifunctional mechanism¹⁰^{21,10}₂, and the incorpora-

to the bifunctional mechanism¹⁰⁻¹⁰₂, and the incorpora-

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Maximportal transmission decreases by XRD and high angle annular dark field

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ity of electro-ostidation of ethanol¹⁰⁴

(HAADF)-transmission electron microscopy (TEM).

Most importantly, the synthesis of multicom And the exact of the surface in the surface of the surface on the surface on the surfa example, and Rue Contest and Rue Contest active of the contest and optical the particular successfully betterostatively and one of the studies and OER were examined in details, and the effects on the Shang et, Au, Pd, Co,

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ides displaying a remarkable performance for OER in
an alkaline electrolyte compared with those crys-
talline counterparts^[18].
Au, Pt and Ru composite alloys have been widely
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m (Ru) and iridium (Ir) ides displaying a remarkable performance for OER in

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is water splitting, while ruthenium (Ru) and iridium (Ir) ides displaying a remarkable performance for OER in
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station reaction (OER)⁰¹ during electrocata-
station contempts^{for}.
Hyric water splitting¹⁰. Tremendous efforts have been and Paul Ru composite alloys Experimentation (external mechanism of the synthesis of Probable and mechanism of the synthesis of Probable decretocallysts.

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Pr-Ru shells were deposited on Au nanowires and

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Au, Pt and Ru composite alloys have been widely
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Au, Pt and Ru composite alloys have been widely
orded due to their excellent electrochemical per-
mance. The mixed solid solution^[19] and core-shel talline counterparts^[18]. Au, Pt and Ru composite alloys have been widely reported due to their excellent electrochemical performance. The mixed solid solution^[19] and core-shell structure have been deeply investigate reported due to their excellent electrochemical performance. The mixed solid solution^[19] and core-shell structure have been deeply investigated. Atomic thin Pt-Ru shells were deposited on Au nanowires and used as elect formance. The mixed solid solution^[19] and core-shell
structure have been deeply investigated. Atomic thin
Pt-Ru shells were deposited on Au nanowires and
used as electrocatalysts for methanol oxidation,
where the Au ca structure have been deeply investigated. Atomic thin
Pt-Ru shells were deposited on Au nanowires and
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where the Au can induce extensive strain towards the
PtRu shells. The c

and environment eartiestic multimated numeral environment and environment can defict the catalysts. The analysts may be easily the catalysts may be easily of the catalysts. In addition, surface and where the Au can induce the entirelysim surfact the control of the cally state of the cally entired to the cally entired to the cally entired to the cally entired or the cally that such in providing the interface engineering are another powerful interior or the teachers are been the relative to the control of Phi meteric explicitely and under the control of Phi and Rusia in the method of Phi and Rusia in the method of the ensimble effect^{ing}, surface strain effe in improving the catalytic activity of the catalytical error is the combinator research of the ensemble effect⁽ⁱⁱ⁾, exhieves the consideration of the ensemble effect⁽ⁱⁱ⁾, exhieves the considered as a mass remarkably o in the vestige wavelevant of the method, and the entanties are copinalized to the entanties of the cell relevant Let the content of both electrocal set and outer intervention and the energy of Alloynia (λ and λ) and λ and λ The solution of the solution of the solution, core-shell and hetero-structure, and μ -

Fiftient stategy in decreasing the cost of precious However, the synthesis of heterostructured multi-

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tion and thus promote reaction activity^[20]. Ru@RuPt
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Howe ly suppress the CO poisoning during methanol oxida-
tion and thus promote reaction activity^[20]. Ru@RuPt
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However, the synthesis of heterostructured multi-
ple-com tion and thus promote reaction activity⁽²⁰⁾. Ru@RuPt
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However, the synthesis of heterostructured multi-
ple-component electrocatalyst and the exploration of
the re also remarkably outperforms Pt/C for alkaline HER^[21].
However, the synthesis of heterostructured multi-
ple-component electrocatalyst and the exploration of
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Herein, low crysta wever, the synthesis of heterostructured multi-

2-component electrocatalyst and the exploration of

regulation mechanism are very limited.

Herein, low crystalline and heterostructured AuPt-

alloys supported on CNTs, de ple-component electrocatalyst and the exploration of
the regulation mechanism are very limited.
Herein, low crystalline and heterostructured AuPt-
Ru/CNTs, were prepared by sequential ethanol reduc-
tion method, and were the regulation mechanism are very limited.

Herein, low crystalline and heterostructured AuPt-

Ru/CNTs, were prepared by sequential ethanol reduc-

tion method, and were further subject to the charac-

terizations by XRD Herein, low crystalline and heterostructured AuPt-
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Ru/CNTs, were prepared by sequential ethanol reduc-
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Ru/CNTs, were prepared by sequential ethanol reduc-

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terizations by XRD and high angle annular dark field

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move the mean term and the mean of COH solved concellented EOK, altaine HER (ivity toward ORR, HER, OER, etc.¹⁹³ by synthesiz-
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trocatalyst toward all these fuel cell relevant reac-
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th Ru/CNTs, were prepared by sequential ethanol reduction method, and were further subject to the characterizations by XRD and high angle annular dark field (HAADF)-transmission electron microscopy (TEM).
The catalytic activ tion method, and were further subject to the charac-
terizations by XRD and high angle annular dark field
(HAADF)-transmission electron microscopy (TEM).
The catalytic activity of heterostructured $(AuPt)_{0x}$ -Ru/
CNTs towa terizations by XRD and high angle annular dark field
(HAADF)-transmission electron microscopy (TEM).
The catalytic activity of heterostructured $(AuP)_{0s}$ -Ru/
CNTs toward electrochemical EOR, alkaline HER
and OER were exa (HAADF)-transmission electron microscopy (TEM).

The catalytic activity of heterostructured $(AuPt)_{as}Ru'$

CNTs toward electrochemical EOR, alkaline HER

and OER were examined in details, and the effects on

the catalytic The catalytic activity of heterostructured $(AuPt)_{0s}$ -Ru/
CNTs toward electrochemical EOR, alkaline HER
and OER were examined in details, and the effects on
the catalytic performance of the element component
are discussed CNTs toward electrochemical EOR, alkaline HER
and OER were examined in details, and the effects on
the catalytic performance of the element component
are discussed.
2. Experimental Section
2.1 Materials
Chloroplatinic e catalytic performance of the element component

discussed.
 Experimental Section

1 Materials

Chloroplatinic acid (H₂PtCl₆·6H₂O, 99%), gold

id chloride trihydrate (HAuCl₄·3H₂O, 99%), ruthe-

metrichloride

th $\# \# \langle I. \text{Electrochem.} \rangle$ 2022, 28(8), 2201241 (3 of 10)
to prepare CNTs-supported heterostructured AuPt-Ru troscopy (XPS, PHI X-tool, Japan) using Al K_{α} as
nanoparticles. First, Ru nanoparticles were prepared X-ray s $#E#(J. Electron). 2022, 28(8), 2201241 (3 of 10)$
to prepare CNTs-supported heterostructured AuPt-Ru troscopy (XPS, PHI X-tool, Japan) using Al K_a as
nanoparticles. First, Ru nanoparticles were prepared
on CNTs. Briefly, 200 mg CN **EXAMPLE CONTS-SUPPORT CONTS-SUPPORT CONTS-SUPPORT CONTS-SUPPORT (SOFT)**

to prepare CNTs-supported heterostructured AuPt-Ru troscopy (XPS, PHI X-tool, Japan) using Al K_a as

nanoparticles. First, Ru nanoparticles were the the complete PCNTs-supported heterostructured AuPt-Ru to scopy (XPS, PHI X-tool, Japan) using Al K_a as
nanoparticles. First, Ru nanoparticles were prepared X-ray source was applied to detect the chemical state
on C **EVALUATE 1999**
 EXECUTE: Example the Herotechem, 2022, 28(8), 2201241 (3 of 10)
 EXECUTE: The proposed is the compare of presence presence of proposed is the chemical state

on CNTs. Briefly, 200 mg CNTs and 83 mg R and refluxed for 1 h. Then, 6 mL $0.2 \text{ mol} \cdot L^{-1}$ NaOH troscopy (HAADF-STEM). **EVALUATION**
 EVALUAT COMPOSE SOLUT THE ADDED INTO THE ADDED INTO THE ADDED INTO THE ABOVE SOL EVALUATION 1989

to prepare CNTs-supported heterostructured AuPt-Ru troscopy (XPS, PHI X-tool, Japan) using Al K_a as

nanoparticles. First, Ru nanoparticles were prepared X-ray source was applied to detect the chemica sure the complete reduction of Ru3+ ions, an extra 2 $\frac{dE}{dt}(L\text{ }Elec$ \n
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Fassupported heterostructured $\Delta uP+Ru$ troscopy (XPS, PHI X-tool, Japan) using $\Delta I K_a$ as
First, Ru nanoparticles were prepared X-ray source was applied to detect the chemical state
fly, 200 mg CNTs and 83 mg RuCl₃ of s **EVACA Electrochem.**) 2022, 28(8), 2201241 (3 of 10)

to prepare CNTs-supported heterostructured AuPt-Ru

troscopy (XPS, PHI X-tool, Japan) using Al K, as

nanoparticles. First, Ru nanoparticles were perpared

X-ray sour th $4E\%$ (*L* Electrochem, 2022, 28(8), 2201241 (3 of 10)

to prepare CNTs-supported heterostructured AuPt-Ru troscopy (XPS, PHI X-tool, Japan) using Al K_{α} as

nanoparticles. First, Ru ananoparticles were prepared X $\text{E}(\mathcal{E} \neq L \mathbb{R})$
to prepare CNTs-supported heterostructured AuPt-Ru troscopy (XPS, PHI X-tool, Japan) using Al K_n as
nanoparticles. First, Ru annoparticles were prepared X -ray somerc was applied to detect the c $\frac{12.22}{2}$ (*L. Electrocheten,*) 2022, 28(8), 2201241 (3 of 10)

to prepare CNTs-supported heterostructured AuPt-Ru troscopy (XPS, PHI X-tool, Japan) using Al K_n as

nanoparticles. First, Ru nanoparticles were prepar **IDEPTE CONTS-supported heterochem**: 2022, 28(8), 2201241 (3 of 10)

to prepare CNTs-supported heterostructured AuPt-Ru troscopy (XPS, PHI X-tool, Japan) using Al K_a as

nanoparticles. First, Ru nanoparticles were prepa **Prepare CNTs-supported CHEMENTA (FORTS EXECUTS EXECUTS)**
 Prepare CNTs-supported CNTs, Ruy troops (XPS, PHI X-tool, Japan) using Al K_a as
 CNTs. Briefly, 200 mg CNTs and 83 mg RuCl₃ of samples. The morphology and to prepare CNTs-supported heterostructured AuPt-Ru

carospoy (XPS, PHI X-tool, Japan) using Al K_n as

non CNTs. Briefly, 200 mg CNTs and 83 mg RuCl₂ of samples. The morphology and the element distri-

were dispersed i

Then, H₂PtCl₆, 6H₂O and HAuCl₄, 3H₂O at an atomic cyclic voltammetry at a
ratio of 1:1 in 20 mL ethanol solution were added in-
taratio of 1:1 in 20 mL ethanol solution were added in-
tarapeature, the cathlysts

(28(8), 2201241 (3 of 10)
troscopy (XPS, PHI X-tool, Japan) using Al K_{α} as
X-ray source was applied to detect the chemical state
of samples. The morphology and the element distri-
bution of the products were performe $(28(8), 2201241 (3 of 10))$
troscopy (XPS, PHI X-tool, Japan) using Al K_{α} as
X-ray source was applied to detect the chemical state
of samples. The morphology and the element distri-
bution of the products were performed $(28(8), 2201241 (3 of 10))$
troscopy (XPS, PHI X-tool, Japan) using Al K_{α} as
X-ray source was applied to detect the chemical state
of samples. The morphology and the element distri-
bution of the products were performed 28(8), 2201241 (3 of 10)

troscopy (XPS, PHI X-tool, Japan) using Al K_{α} as

X-ray source was applied to detect the chemical state

of samples. The morphology and the element distri-

bution of the products were perfo 28(8), 2201241 (3 of 10)

troscopy (XPS, PHI X-tool, Japan) using Al K_{α} as

X-ray source was applied to detect the chemical state

of samples. The morphology and the element distri-

bution of the products were perfo 28(8), 2201241 (3 of 10)
troscopy (XPS, PHI X-tool, Japan) using Al K_{α} as
X-ray source was applied to detect the chemical state
of samples. The morphology and the element distri-
bution of the products were performed 2.28(8), 2201241 (3 of 10)
troscopy (XPS, PHI X-tool, Japan) using Al K_a as
X-ray source was applied to detect the chemical state
of samples. The morphology and the element distri-
bution of the products were performed (8), 2201241 (3 of 10)
scopy (XPS, PHI X-tool, Japan) using Al K_{α} as
ay source was applied to detect the chemical state
samples. The morphology and the element distri-
ion of the products were performed in high-angle 电化学(*J. Electrochem.*) 2022, 28(8), 2201241 (3 of 10)
rostructured AuPt-Ru troscopy (XPS, PHI X-tool, Japan) using Al K_{α} as
rticles were prepared X-ray source was applied to detect the chemical state
Ts and 83 mg Ru

annoparticles. First, Ru nanoparticles were prepared

on CNTs. Brristy, 200 mg CNTs and 83 mg RuC(1) of samples. The morphology and the clement disti-

one dispersed into 130 ml. absolute ethanol, heated

bution of the pr on CNTs. Briefly, 200 mg CNTs and 83 mg RuCl,
or Samples. The morphology and the clement distri-
were dipercolated by 130 mla basolute ethanol, heated bution of the products were performed in high-angle
to 10 o⁻C in an were dispersed into 130 mL absolute channol, heated

to 110 °C in an onl hand at staring rate of 300 c·min⁻¹ annular dark-field scaning transition electron species

and refluxed for 1 h. Then, 6 mL 0.2 mol -L⁻¹ NaOH
 to 110 °C in an oil bath at a stirring rate of 300 r·min⁻¹ annular dark-field scanning transition electron spec-
and refluend for 1 b. Then, 6 mL 0.2 mol-1: NaOH incosopy (HAADF-STEM).
Substitution was added into the ab and refluxed for 1 h. Then, 6 mL 0.2 mol \cdot L³ NaOH troscopy (HAADF-STEM).

Solution was added into the above solution and **2.4 Electrochemical Measurements**

started for another 2 h for reduction. Finally, to entime a 1L 0.2 mol L^1 NaOH troscopy (HAADF-STEM).

above solution and **2.4 Electrochemical Measurements**

above solution and **2.4 Electrochemical Measurements**

Ruⁱ⁺ ions, an extra 2 ethanol for 1 h to make a 1 mg·L¹ homog solution was added into the above solution and

stirred for another 2 h for reduction. Finally, to can-

stirred for another 2 h for reduction of Ru² ions, an extra 2

started in started alomogeneous cat-

mL 0.2 mol -L stirred for another 2 h for reduction. Finally, to en-
stare the complete readcroin of Ru¹ ions, an extra 2
mL 0.2 mol -L² handle feaduction of Ru¹ ions, an extra 2
mL 0.2 mol -L² haven be complete readcribution w sure the complete reduction of Ru" ions, an extra 2

mLn of 2: ml on the all mg-1.³ homogeneous cat-

mL of 2: ml of 2: "No MF solution was further added in-

mL eths above solution and stirred for another 30 min.

the mL 0.2 mol L¹ NaOH solution was further added in-

the glassy carbon electrode (6 mm in diameter). After

The podates were precipitated by centrifugation, evaporating the solvent naturally in air, 10 µL of

the above so er added in-

anyst ink. Then, 15 µL of catalyst ink was dropped on

ther 30 min.

the glassy carbon electrode (6 mm in diameter). After

tritringation,

covaporating the solvent naturally in air, 10 µL of

ethanol, re-
 to the above solution and stirred for another 30 min. the glassy carbon electrode (6 mm in diameter). After
The products were precipitated by centrifugation, exceparating the solvent naturally in air, 10 μ L of
Washed t The products were precipitated by centrifugation,

waporating the solvent naturally in air, 10 μ L of

wasked three times with DI water and ethanol, re-

2 zwt% Nafion solution was drop cast on top of the

spectively, a washed three times with DI water and ethanol, re-
specifyity, and finally drivation associates exceeding the secure of the celestrochemis-specificaly, and finally drivation is variation as to entable anturally in air. The spectively, and finally dried in a vacuum oven at 60 eatalyst and dried naturally in air. The electrochemic The bitanical product is denoted as RuCNTs. The olitical product is the error of AuPt and SC and performance was C. The obtained product is denoted as Ru/CNTs.

C. The hetrostructured (AuPh₀-Ru/CNTs sample vast electrochemical vorkstation by using a standard

obtained by concurrent reduction of AuPh alloy at the three-electrode ce The heterostructured (AuPt)_a-Ru/CNTs sample was
electrochemical vonkstation by using a standard
obtained by concurrent reduction of AuPt alloy at the three-clectrode cell. The catalyst-covered glassy ear-
otheric atio o obtained by concurrent reduction of AuPt alloy at the

three-cleetrode cell. The catalyst-covered glassy car-

denote ratio of AuPt = 1:1 on Ru/CNTs using the bon electrode served as the working electrode and the

erthano atomic ratio of Au: $Pr = 1:1$ on Ru/CNTs using the

enhanol reduction method. Firstly, 60 mg of Ra/CNTs — platinum-wire electrode was used as the conter elec-

ensus dispersed in absolute ethanol (25 mL) solution,

trode. T erhanol reduction method. Firstly, 60 mg of Ru/CNTs
platinum-wire electrode was used as the counter elec-
was dispersed in absolute ethanol (25 mL) solution, trode. The lectrocatalytic performance toward ethanol
heated to was dispersed in absolute ethanol (25 mL) solution,

heade to Ro ^oC and Subsequently, 4 mL 0.2 mol -1-1² ethanol was carried out in 1.0 mol -1-1² enhanol and

Subsequently, 4 mL 0.2 mol -1-1² NGOH solution was a c heated to 80 °C and stirred at a rate of 300 r·min⁻¹. oxidation was carried out in 1.0 mol -L⁻¹ channel and
subsequently, 4 mL 0.2 mol -L³ NoOH solution was 1.0 mol -L³ KOH aqueous solution in a potential
dided in Subsequently, 4 mL 0.2 mol - L⁺ NoOH solution was 1.0 mol - L⁺ KOH aqueous solution in a potential
added into the above solution and stirred for 30 min. window from -0.85 to 0.2 V (vs. 1 [g/1gO] uhrough
doded into the added into the above solution and stirred for 30 min. window from -0.85 to 0.2 V (vs. Hg/HgO

Then, H₂PtCl₃, -6H₂O and HAuCl₄-3H₂O at an atomic explice voltammetry at a scanning rate of 5 ratio of 1:1 in 20 mL e io of 1:1 in 20 mL ethanol solution were added in-

and mercury/mercurous oxide electrode (Hg/HgO) was

the above solution at a rate of 5 mL-h^t and main-

employed as the referince clectred. The clectro-

end at 80 °C f to the above solution at a rate of S mL-h³ and main-

employed as the reference electrode. The electro-

tand at 80 °C for 1.5 h. After cooling down to room catabytic activity toward alkatine hydrogen evolution

tempera tained at 80 °C for 1.5 h. After cooling down to room

catalytic activity toward alkaline hydrogen evolution

temperature, the catalysts were collected by centrific-

and oxygen evolution was performed in 1.0 mol -1-¹
 $(28(8), 2201241 (3 of 10))$
troscopy (XPS, PHI X-tool, Japan) using Al K_{α} as
X-ray source was applied to detect the chemical state
of samples. The morphology and the element distri-
bution of the products were performed an) using Al K_{α} as
t the chemical state
if the element distri-
ormed in high-angle
ition electron spec-
urements
if and sonicated in
⁻¹ homogeneous cat-
ink was dropped on
i in diameter). After
y in air, 10 μ L . 28(8), 2201241 (3 of 10)
troscopy (XPS, PHI X-tool, Japan) using Al K_{α} as
X-ray source was applied to detect the chemical state
of samples. The morphology and the element distri-
bution of the products were perform . 28(8), 2201241 (3 of 10)
troscopy (XPS, PHI X-tool, Japan) using Al K_a as
X-ray source was applied to detect the chemical state
of samples. The morphology and the element distri-
bution of the products were performed 28(8), 2201241 (3 of 10)
troscopy (XPS, PHI X-tool, Japan) using Al K_{α} as
X-ray source was applied to detect the chemical state
of samples. The morphology and the element distri-
bution of the products were performed 28(8), 2201241 (3 of 10)
troscopy (XPS, PHI X-tool, Japan) using Al K_a as
X-ray source was applied to detect the chemical state
of samples. The morphology and the element distri-
bution of the products were performed in 28(8), 2201241 (3 of 10)
troscopy (XPS, PHI X-tool, Japan) using Al K_α as
X-ray source was applied to detect the chemical state
of samples. The morphology and the element distri-
bution of the products were performed i $(28(8), 2201241 (3 \text{ of } 10))$
troscopy (XPS, PHI X-tool, Japan) using Al K_a as
X-ray source was applied to detect the chemical state
of samples. The morphology and the element distri-
bution of the products were performed Electrochemical workstation by using Al K_a as
X-ray source was applied to detect the chemical state
of samples. The morphology and the element distri-
bution of the products were performed in high-angle
annular dark-fie troscopy (XPS, PHI X-tool, Japan) using Al K_{α} as
X-ray source was applied to detect the chemical state
of samples. The morphology and the element distri-
bution of the products were performed in high-angle
annular da X-ray source was applied to detect the chemical state
of samples. The morphology and the element distri-
bution of the products were performed in high-angle
annular dark-field scanning transition electron spec-
troscopy (of samples. The morphology and the element distri-
bution of the products were performed in high-angle
annular dark-field scanning transition electron spec-
troscopy (HAADF-STEM).
2.4 Electrochemical Measurements
The ca bution of the products were performed in high-angle
annular dark-field scanning transition electron spec-
troscopy (HAADF-STEM).
2.4 Electrochemical Measurements
The catalysts were dispersed and sonicated in
ethanol for 1 annular dark-field scanning transition electron spec-
troscopy (HAADF-STEM).
2.4 Electrochemical Measurements
The catalysts were dispersed and sonicated in
ethanol for 1 h to make a 1 mg·L⁻¹ homogeneous cat-
alyst ink. electron spec-
 ents

sonicated in

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ir, 10 μ L of

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electrochemi-

a CHI-660E

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crode and the

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oward ethanol

n a troscopy (HAADF-STEM).
 2.4 Electrochemical Measurements

The catalysts were dispersed and sonicated in

ethanol for 1 h to make a 1 mg·L⁻¹ homogeneous cat-

alyst ink. Then, 15 μ L of catalyst ink was dropped on

t AADF-STEM).
 rochemical Measurements

alysts were dispersed and sonicated in

1 h to make a 1 mg·L¹ homogeneous cat-

hen, 15 µL of catalyst ink was dropped on

arbon electrode (6 mm in diameter). After

the solvent n 2.4 Electrochemical Measurements
The catalysts were dispersed and sonicated in
ethanol for 1 h to make a 1 mg·L¹ homogeneous cat-
alyst ink. Then, 15 μ L of catalyst ink was dropped on
the glassy carbon electrode (6 m The catalysts were dispersed and sonicated in
ethanol for 1 h to make a 1 mg·L⁻¹ homogeneous cat-
alyst ink. Then, 15 μ L of catalyst ink was dropped on
the glassy carbon electrode (6 mm in diameter). After
evaporatin -1 ethanol for 1 h to make a 1 mg·L⁻¹ homogeneous cat-
alyst ink. Then, 15 μ L of catalyst ink was dropped on
the glassy carbon electrode (6 mm in diameter). After
evaporating the solvent naturally in air, 10 μ L of
2w alyst ink. Then, 15 μ L of catalyst ink was dropped on
the glassy carbon electrode (6 mm in diameter). After
evaporating the solvent naturally in air, 10 μ L of
2wt% Nafion solution was drop cast on top of the
catalys the glassy carbon electrode (6 mm in diameter). After
evaporating the solvent naturally in air, 10 μ L of
2wt% Nafion solution was drop cast on top of the
catalyst and dried naturally in air. The electrochemi-
cal perfo evaporating the solvent naturally in air, 10 μL of 2wt% Nafion solution was drop cast on top of the catalyst and dried naturally in air. The electrochemical performance was investigated on a CHI-660E electrochemical work 2wt% Nafion solution was drop cast on top of the catalyst and dried naturally in air. The electrochemical performance was investigated on a CHI-660E electrochemical workstation by using a standard three-electrode cell. Th catalyst and dried naturally in air. The electrochemical performance was investigated on a CHI-660E
electrochemical workstation by using a standard
three-electrode cell. The catalyst-covered glassy car-
bon electrode serv ally in air. The electrochemi-
nvestigated on a CHI-660E
ation by using a standard
catalyst-covered glassy car-
he working electrode and the
was used as the counter elec-
c performance toward ethanol
ut in 1.0 mol·L¹ et cal performance was investigated on a CHI-660E
electrochemical workstation by using a standard
three-electrode cell. The catalyst-covered glassy car-
bon electrode served as the working electrode and the
platinum-wire ele electrochemical workstation by using a standard
three-electrode cell. The catalyst-covered glassy car-
bon electrode served as the working electrode and the
platinum-wire electrode was used as the counter elec-
trode. The three-electrode cell. The catalyst-covered glassy car-
bon electrode served as the working electrode and the
platinum-wire electrode was used as the counter elec-
trode. The electrocatalytic performance toward ethanol
oxi bon electrode served as the working electrode and the
platinum-wire electrode was used as the counter elec-
trode. The electrocatalytic performance toward ethanol
oxidation was carried out in 1.0 mol \cdot L⁻¹ ethanol an -1 platinum-wire electrode was used as the counter electrode. The electrocatalytic performance toward ethanol oxidation was carried out in 1.0 mol \cdot L⁻¹ ethanol and 1.0 mol \cdot L⁻¹ kOH aqueous solution in a potential trode. The electrocatalytic performance toward ethanol
oxidation was carried out in 1.0 mol \cdot L⁻¹ ethanol and
1.0 mol \cdot L⁻¹ KOH aqueous solution in a potential
window from -0.85 to 0.2 V (vs. Hg/HgO) through
eyc tic performance toward ethanol
out in 1.0 mol \cdot L⁻¹ ethanol and
ueous solution in a potential
0.2 V (vs. Hg/HgO) through
a scanning rate of 50 mV \cdot s⁻¹
s oxide electrode (Hg/HgO) was
rence electrode. The electro oxidation was carried out in 1.0 mol \cdot L⁻¹ ethanol and
1.0 mol \cdot L⁻¹ KOH aqueous solution in a potential
window from -0.85 to 0.2 V (vs. Hg/HgO) through
eyclic voltammetry at a scanning rate of 50 mV \cdot s⁻¹
an 1.0 mol \cdot L⁻¹ KOH aqueous solution in a potential
window from -0.85 to 0.2 V (vs. Hg/HgO) through
eyclic voltammetry at a scanning rate of 50 mV \cdot s⁻¹
and mercury/mercurous oxide electrode (Hg/HgO) was
employed as window from -0.85 to 0.2 V (vs. Hg/HgO) through
eyclic voltammetry at a scanning rate of 50 mV·s⁻¹
and mercury/mercurous oxide electrode (Hg/HgO) was
employed as the reference electrode. The electro-
catalytic activity eyclic voltammetry at a scanning rate of 50 mV·s⁻¹
and mercury/mercurous oxide electrode (Hg/HgO) was
employed as the reference electrode. The electro-
catalytic activity toward alkaline hydrogen evolution
and oxygen ev and mercury/mercurous oxide electrode (Hg/HgO) was
employed as the reference electrode. The electro-
catalytic activity toward alkaline hydrogen evolution
and oxygen evolution was performed in 1.0 mol·L¹
KOH aqueous sol entry/mercurous oxide electrode (Hg/HgO) was
d as the reference electrode. The electro-
activity toward alkaline hydrogen evolution
gen evolution was performed in 1.0 mol·L¹
ueous solution by linear sweep voltammetry
ra employed as the reference electrode. The electro-
catalytic activity toward alkaline hydrogen evolution
and oxygen evolution was performed in 1.0 mol·L¹
KOH aqueous solution by linear sweep voltammetry
at a scan rate of catalytic activity toward alkaline hydrogen evolution
and oxygen evolution was performed in 1.0 mol·L⁺
KOH aqueous solution by linear sweep voltammetry
at a scan rate of 10 mV·s⁻¹. The stability of the electro-
cataly

**The distance of the adjacent fringes was measured to

The KRD patterns of the aspergared Ru/CNTs, be 2.32 Å in the HRTEM image (Figure 2(b), con-

AuPt/CNTs, (AuPt_{Me}-Ru/CNTs adjRupt/Au/CNTs sistent with the XRD result.** The XRD patterns of the as-prepared Ru/CNTs,

be 2.32 Å in the HRTEM image (Figure 2(b)), con-

AuPt/CNTs (AuPt)₀₂-Ru/CNTs and RuPt/Lu/CNTs sistent with the XRD result. This interplanar distance

are shown in Figure 1. (AuPt)_{0.5}-Ru alloy NPs was calculated to be 2.314 Å^[22]. (AuPt)-Ru, instead of Ru@AuPt core-shell structure AuPt/CNTs, (AuPt)_{0x}-Ru/CNTs and RuPtAu/CNTs sistent with the XRD result. This interplanar distance
are shown in Figure 1. The Ru/CNTs displayed a of AuPt (111) for the (AuPt)_{0x}-Ru is larger than that
of a super than t are shown in Figure 1. The Ru/CNTs displayed a of AuPt (111) for the (AuPt_{)bar}-Ru is larger than that
broad peak of Ru(101) at 43.7° due to the presence of Pr(111) (2274), for
the comparine constrained to the presence o broad peak of Ru(101) at 43.7° due to the presence
of Pt(111) (2.27Å), further confirming the expansive
of amorphous Ru nanogarticies (NPs), which was strain indeted on Pt by the heterostructured (AuPt)_{0x}-Ru/CNTs displa of amorphous Ru nanoparticles (NPs), which was

strain induced on Pt by the heterostructured (AuPl_{0s}-

well observed for (AuPl_{0s}-Ru/CNTs⁷³²²², while the Ru NPs. Morocor, a faded diffuse ring in the scleet

(AuPl₀ well observed for $(\text{ArlP})_{ab}$ -Ru/CNTs¹²¹, while the

Ru NPs. Moreover, a fided diffuse ring in the select-

(AuPt_{)u}-Ru/CNTs (siphayed a peak at 38.89° corresponding to AuPt

(111) and phase oncided to AuPt in Figure (AuPt_{0s}-RwCNTs displayed a peak at 38.89° corre-

ed area electron diffraction (SAED) pattern (the inset

equading to AuPt (111). The peak associated to AuPth in Figure 2(b)) was attributed to the amorphous char-

(111) sponding to AuPt (111). The peak associated to AuPt

in Figure 2(b)) was attributed to the amorphous

(111) and observed from the $(AuPt)_{n}Rw/CNTs$ was

located between Au (111), and Pt (111), and Pt (111), and Pt (111), an 11) and observed from the $(AuP1)_{\text{ar}}Ru/CNTs$ was acter of Ru NPs. The energy dispersive X-ray (EDX)
ated between Au (111) and Plt (111), and closer to elemental mapping images (Figure 2(c-b) revealed
to for Pt (111), indi located between Au (111) and Pt (111), and closer to

clemental mapping images (Figure 2(c-e)) revealed

that of Pt (111), indicating the formation of Au-Pt al-

by the smaller March au and Pt elements overlapped with eac that of Pt (111), indiceding the formation of Au-Pt al-

that Au and Pt elements overlapped with each other

loy. The smaller Bragg angle shift of the AuP(111) is very well, indicating that the we elements are home-

dica

EMPLEM in Equal to the Retrochemical measurements.
 EMPLEM in the electrochemical measurements.
 EMPLEM in the electrochemical measurements.
 EMPLEM in the electrochemical measurements.

The distance of the adjac $# \# \# (J. \text{Electrochem.}) 2022, 28(8), 2201241 (4 of 10)$

performed for all the electrochemical measurements.
 3 Results and Discussion The distance of the adjacent fringes was

The XRD patterns of the as-prepared Ru/CNTs, be 2 $\text{#E#}(J. Electrochem.)$ 2022, 28(8), 2201241 (4 of 10)

formed for all the electrochemical measurements. ter of 5.3 ± 0.2 nm and are evenly loaded on CNTs.
 Results and Discussion

The distance of the adjacent fringes was meas **EMPERENT AUTE AUTOM EXAMPLE 1** (Retrochem) 2022, 28(8), 2201241 (4 of 10)
 EMPERENT AUPRENT AUPRENT AUTE AUTE AUTOM CONTS.
 ALCORED THE SESUITS and Discussion

The XRD patterns of the as-prepared Ru/CNTs, be 2.32 Å **EVACATE SET ALSO THE SET AS A SET AND THE RUCKLE (AUPT)** or
 EVACATE AT A SESSURE SHOW IS A SET AND PEREOTED IN THE SET AND PRESENT AND PRESENT AND PRESENTS of the as-prepared Ru/CNTs, the CATE of the adjacent fringes w $\pm \frac{\text{ft2#}}{\text{C}}$ (*Electrochem.*) 2022, 28(8), 2201241 (4 of 10)
 performed for all the electrochemical measurements. ter of 5.3 \pm 0.2 mn and are evenly loaded on CNTs.
 Broad Discutsion Che as-prepared Ru/CNTs, **EVALUATE AMORE (EXECUTE AMORE AMORE AMORE AT A SUPPRESED (AUP)** and observed from the (AuP)³ amore (11) and observed from the (AUP)³ amore (11) and observed from the (AUP)³ amore (11) and observed from the (AP)³ **EVALUATE ALTERT (AUPT)** and $\mathbb{R}(\mathbb{R}^n)$, while the seadent of $\mathbb{R}(\mathbb{R}^n)$, while the seadent of $\mathbb{R}(\mathbb{R}^n)$ and $\mathbb{R}(\mathbb{R}^n)$ and $\mathbb{R}(\mathbb{R}^n)$ and $\mathbb{R}(\mathbb{R}^n)$ and $\mathbb{R}(\mathbb{R}^n)$ and (AuPt)0.5-Ru/CNTs displayed a peak at 38.89^毅 corre-**Example 12**
 Example 12 (*LE Rectrochemical measurements.* ter of 5.3 ± 0.2 mm and are evently loaded on CNTs.
 3 Results and Discussion

The distance of the algorent frames (in and Φ and Φ and Φ and Φ an (1) the expectation of the electrocheme and the electrocheme and or CNTs.
 111) and **Discussion**

The distance of the adjacent fringes was measured to

The NRD patents **and Discussion**

The interparameter of the adjace **EVALUAT CONDIVE TO THE CONDENSISE (AUTOMBET AUTOMBET AND SOLUTRA (III) and Discussion of AUTOMBET AUTOMBET AUTOMBET AND PRESENT AND PRESENT THE GENT AND PARTICULTS, (AuPUCNTS, (AuPUCNTS, (AuPUCNTS, (AuPUCNTS, CAUPUCNTS,** that of Pt (111), indicating the formation of Au-Pt alle (εφαγαι and the electrochemical measurements. The smaller of 5.3 ± 0.2 mm and are evenly loaded on CNTs.
 3 Results and Discussion The distance of the algoent fringes was measure of the action of the automore of th the $\frac{1}{2}$ (E $\frac{P_+}{P_+}(f)$ Electrochemical measurements. The of 5.3 ± 0.2 mm and are eventy loaded on CNTs.
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 3 Results and Discussion The distance of the aigeneral frages was measured to The XRD patterns of the as-prepare performed for all the electrochemical measurements. ter of 5.3 \pm 0.2 mm and are eventy loaded on CNTs.
 ITEN SIM SHOCUSSOM The distance of the algoent fringes was measured to

The XRD patterns of the as-prepared Ru/C 28(8), 2201241 (4 of 10)
ter of 5.3 \pm 0.2 nm and are evenly loaded on CNTs.
The distance of the adjacent fringes was measured to
be 2.32 Å in the HRTEM image (Figure 2(b)), con-
sistent with the XRD result. This interp 28(8), 2201241 (4 of 10)
ter of 5.3 \pm 0.2 nm and are evenly loaded on CNTs.
The distance of the adjacent fringes was measured to
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sistent with the XRD result. This interp 28(8), 2201241 (4 of 10)
ter of 5.3 \pm 0.2 nm and are evenly loaded on CNTs.
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sistent with the XRD result. This interp 28(8), 2201241 (4 of 10)
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sistent with the XRD result. This interp 28(8), 2201241 (4 of 10)
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sistent with the XRD result. This interp 28(8), 2201241 (4 of 10)
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The distance of the adjacent fringes was measured to
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sistent with the XRD result ter of 5.3 \pm 0.2 nm and are evenly loaded on CNTs.
The distance of the adjacent fringes was measured to
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sistent with the XRD result. This interplanar distance
of AuPt (1 The distance of the adjacent fringes was measured to
be 2.32 Å in the HRTEM image (Figure 2(b)), con-
sistent with the XRD result. This interplanar distance
of AuPt (111) for the (AuPt)_{0.5}-Ru is larger than that
of Pt(1 be 2.32 Å in the HRTEM image (Figure 2(b)), consistent with the XRD result. This interplanar distance of AuPt (111) for the (AuPt)_{0.5}-Ru is larger than that of Pt(111) (2.27Å), further confirming the expansive strain in sistent with the XRD result. This interplanar distance
of AuPt (111) for the (AuPt)_{0.5}-Ru is larger than that
of Pt(111) (2.27Å), further confirming the expansive
strain induced on Pt by the heterostructured (AuPt)_{0.5} AuPt (111) for the (AuPt)_{0s}-Ru is larger than that Pt(111) (2.27Å), further confirming the expansive
ain induced on Pt by the heterostructured (AuPt)_{0s}-
NPs. Moreover, a faded diffuse ring in the select-
area electron of Pt(111) (2.27Å), further confirming the expansive
strain induced on Pt by the heterostructured $(AuPt)_{0s}$ -
Ru NPs. Moreover, a faded diffuse ring in the select-
ed area electron diffraction (SAED) pattern (the inset
in (2.27Å), further confirming the expansive
ced on Pt by the heterostructured $(AuPt)_{0.5}$ -
Ioreover, a faded diffuse ring in the select-
etron diffraction (SAED) pattern (the inset
(b)) was attributed to the amorphous charg the expansive
tured (AuPt)_{0.5}-
ng in the select-
attern (the inset
morphous char-
/e X-ray (EDX)
(c-e)) revealed
with each other
nents are homo-
l solution alloy.
red on the same
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neterostructured
ex-she strain induced on Pt by the heterostructured $(AuPt)_{0.5}$
Ru NPs. Moreover, a faded diffuse ring in the select-
ed area electron diffraction (SAED) pattern (the inset
in Figure 2(b)) was attributed to the amorphous char-
a Ru NPs. Moreover, a faded diffuse ring in the select-
ed area electron diffraction (SAED) pattern (the inset
in Figure 2(b)) was attributed to the amorphous char-
acter of Ru NPs. The energy dispersive X-ray (EDX)
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[-ray (EDX)
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re evaluated
hanol, using
0.072 V to
 $^{-1}$. As shown
d the simil ed area electron diffraction (SAED) pattern (the inset
in Figure 2(b)) was attributed to the amorphous char-
acter of Ru NPs. The energy dispersive X-ray (EDX)
elemental mapping images (Figure 2(c-e)) revealed
that Au and in Figure 2(b)) was attributed to the amorphous character of Ru NPs. The energy dispersive X-ray (EDX) elemental mapping images (Figure 2(c-e)) revealed that Au and Pt elements overlapped with each other very well, indica $\frac{\text{H} \& \frac{\text{L}}{\text{L}} \& (J. \text{Electrochem.}) 2022, 28(8), 2201241 (4 of 10)}{\text{mical measurements.}}$ for of 5.3 ± 0.2 nm and are evenly loaded on CNTs.

The distance of the adjacent fringes was measured to

the s-prepared Ru/CNTs, be 2.32 Å in t

acter of Ru NPs. The energy dispersive X-ray (EDX)
elemental mapping images (Figure 2(c-e)) revealed
that Au and Pt elements overlapped with each other
very well, indicating that the two elements are homo-
geneously mixed elemental mapping images (Figure 2(c-e)) revealed
that Au and Pt elements overlapped with each other
very well, indicating that the two elements are homo-
geneously mixed and form AuPt solid solution alloy.
However, Ru, A that Au and Pt elements overlapped with each other
very well, indicating that the two elements are homo-
geneously mixed and form AuPt solid solution alloy.
However, Ru, Au and Pt were observed on the same
NPs, but did no very well, indicating that the two elements are homogeneously mixed and form AuPt solid solution alloy.
However, Ru, Au and Pt were observed on the same
NPs, but did not overlap very well with each other
(Figure 2(f)). Th geneously mixed and form AuPt solid solution alloy.
However, Ru, Au and Pt were observed on the same
NPs, but did not overlap very well with each other
(Figure 2(f)). This indicates that heterostructured
(AuPt)-Ru, instea However, Ru, Au and Pt were observed on the same
NPs, but did not overlap very well with each other
(Figure 2(f)). This indicates that heterostructured
(AuPt)-Ru, instead of Ru@AuPt core-shell structure
or evenly mixed Ru NPs, but did not overlap very well with each other
(Figure 2(f)). This indicates that heterostructured
(AuPt)-Ru, instead of Ru@AuPt core-shell structure
or evenly mixed RuAuPt alloy were formed.
EOR activities of all the (Figure 2(f)). This indicates that heterostructured

(AuPt)-Ru, instead of Ru@AuPt core-shell structure

or evenly mixed RuAuPt alloy were formed.

EOR activities of all the catalysts were evaluated

in 1 mol·L¹ KOH con (AuPt)-Ru, instead of Ru@AuPt core-shell structure
or evenly mixed RuAuPt alloy were formed.
EOR activities of all the catalysts were evaluated
in 1 mol·L⁻¹ KOH containing 1 mol·L⁻¹ ethanol, using
cyclic voltammetry (or evenly mixed RuAuPt alloy were formed.

EOR activities of all the catalysts were evaluated

in 1 mol·L¹ KOH containing 1 mol·L¹ chanol, using

cyclic voltammetry (CV), sweeping from 0.072 V to

1.12 V (vs. RHE) at EOR activities of all the catalysts were evaluated
in 1 mol·L¹ KOH containing 1 mol·L¹ ethanol, using
eyclic voltammetry (CV), sweeping from 0.072 V to
1.12 V (vs. RHE) at a scan rate of 50 mV·s⁻¹. As shown
in Figur in 1 mol·L⁻¹ KOH containing 1 mol·L⁻¹ ethanol, using
eyclic voltammetry (CV), sweeping from 0.072 V to
1.12 V (vs. RHE) at a scan rate of 50 mV·s⁻¹. As shown
in Figure 3(a), all these catalysts displayed the similar eyclic voltammetry (CV), sweeping from 0.072 V to
1.12 V (vs. RHE) at a scan rate of 50 mV·s⁻¹. As shown
in Figure 3(a), all these catalysts displayed the similar
forward peak potential around 0.85 V. As shown in
Figure $\sqrt{J_{\rm b}}$ 1.12 V (vs. RHE) at a scan rate of 50 mV·s⁻¹. As shown
in Figure 3(a), all these catalysts displayed the similar
forward peak potential around 0.85 V. As shown in
Figure 3(b), the peak current density of $(AuPt)_{0.5}Ru$ /
C in Figure 3(a), all these catalysts displayed the similar
forward peak potential around 0.85 V. As shown in
Figure 3(b), the peak current density of $(AuPt)_{0.5}Ru$
CNTs was 21.4 A $\cdot mg^{t}{}_{n}$, which is much higher than
tho forward peak potential around 0.85 V. As shown in
Figure 3(b), the peak current density of $(AuPt)_{0.5}Ru$ /
CNTs was 21.4 A $\cdot mg^{1}_{\text{R}}$, which is much higher than
those of $AuPt/CNTs$ (2.69 A $\cdot mg^{1}_{\text{R}}$), $RuPtu\omega/CNTs$
(0.92 A Figure 3(b), the peak current density of $(AuPt)_{0.5}Ru/CNTs$ was 21.4 A mg^{-1} _R, which is much higher than those of AuPt/CNTs (2.69 A mg^{-1} _R), RuPtAu/CNTs (0.92 A mg^{-1} _R) and Pt/C (0.51 A mg^{-1} _R), indicating the ex Expansive strain imposed on PL

Figure 2(a-b) shows in the typical transmission elec-

EVIS was 21.4 A mg k, which is much higher than

CNTs, which display spherical shapes with a diame-

CNTs, which display spherical sha Figure 2(a-b) shows the typical transmission elec-

Eigure 3(b), the peak current density of $(AuP)_{0x}$ -Ru)

CNTs, which display spherical shapes with a diame-

CNTs, which is much higher than the highest $(0.92 \text{ A} \cdot \text{$

 $(AuPt)_{0.5}$ -Ru/CNTs^[23].

 $\frac{\text{H} \& \frac{\text{H}}{\text{L}}(J. \text{Electrochem.}) 2022, 28(8), 2201241 (6 of 10))}{\text{co relation for}}$

v of ethanol oxidation for related to the amorphous-like state of AuPt in the heterostructured (AuPt)_{0.5}-Ru.

VC catalyst. We have further stud

 $\frac{\text{#L#}(J. \text{Electrochem.}) 2022, 28(8), 2201241 (6 of 10)}{\text{Table 1 Comparison in the activity of ethanol oxidation for the Aupt/CNTs and RuptAu/CNTs}} \quad \text{related to the amorphous-like state of Aupt in the heterostructured (Aupt)₀₃-Ru. We have further studied the catalytic activity and dratalytic activity and dratalytic of the (Aupt)₀₃-Ru/CNTs by CA experiments at 0.7 V (vs. RHE). and the results are presented in$ the AuPt/CNTs (AuPt)_{0.5}-Ru/CNTs and RuPtAu/CNTs

the AuPt in the activity of ethanol oxidation for

the AuPt/CNTs, (AuPt)_{0.5}-Ru/CNTs and RuPtAu/CNTs

catalysts, as well as Pt/C catalyst.

Catalyst I_{peak} , A · mg_R the *H*/ $\frac{E}{\mathcal{F}}(J. Electrochem.)$ 2022, 28(8), 2201241 (6 of 10)

mparison in the activity of ethanol oxidation for

related to the amorphous-like state of AuPt in the

NTs, (AuPt_{)0.5}-Ru/CNTs and RuPtAu/CNTs

catalysts, as $\begin{tabular}{l|c|c|c|c} \hline &\textbf{#12.22}\qquad\hline \textbf{#2.23}\qquad\hline \textbf{#3.24}\qquad\hline \textbf{#3.25}\qquad\hline \textbf{#4.26}\qquad\hline \textbf{#5.26}\qquad\hline \textbf{#5.26}\qquad\hline \textbf{#5.26}\qquad\hline \textbf{#5.26}\qquad\hline \textbf{#5.26}\qquad\hline \textbf{#5.26}\qquad\hline \textbf{#5.26}\qquad\hline \textbf{#5.26}\qquad\hline \textbf{$ $\frac{\text{right } \# \{E\}^{\infty}(L\ \textit{Elemochem.}) \cdot 2022,28(8),2201241 \text{ (6 of 10)} }{1000 \text{ cm}^2 \text{ km}^2 \text{ cm}^2 \text{ cm}^$. In order to investigate the stability of the prepared **This 1** Comparison in the activity of changed the contentro-oxidation for the changed (AuPt)_{M-}Rku²CNTs and BaPackuCNTs (AuPt)_{M-}Rku²CNTs and BaPackuCNTs (AuPt)_{M-}Rku²CNTs and BaPackuCNTs (AuPt)_{M-}Rku²CNTs an **Table 1** Comparison in the activity of esthand oridation for

the AuPtONTs, (AuPt)₀-RuCNTs and RuPt/LuCNTs

the Herecostructured (AuPt)₀₀-RuL

catalysts, as well as Pt/C catalyst.
 $\frac{1}{\mu_{\text{ph}}A\cdot m_{\text{ph}}a^*}$ $\frac{1$ the AuPtCNTs, (AuPt₁)_n-RuCNTs and RuPtAuCNTs hetrostructured (AuPt_{1)n}-RuCNTs and RuPtAuCNTs hetrostructured (AuPt_{1)n}-RuCNTs hy CA experiments

Rundom in Figure 3(d), After each phonon specifies (AuPt)_n-RuCNTs by eatalysts, as well as PVC catalyst

We have further studied the catalytic activity and

Catalyst

Catalyst

Catalyst

Catalyst

Ra/ADPCNTs

Ra/ADPCNTs

Ra/ADPCNTs

(AuPP_{AD}-Ra/CNTs

2.09

3.02

Tigure 3(d). ARer cather c Catalyst $J_{\text{tot}}A \cdot m_{\text{B}}m$

Catalyst $J_{\text{tot}}A \cdot m_{\text{B}}m$
 ≈ 0.92
 3.02
 3.0 Caulyst

Caulyst $f_{\text{ext}}A\text{-mg}_6A''$ and $f_{\text{ext}}/X_{\text{ext}}$ and $f_{\$ RuAuPVCNTs 0.92 3.47

AuPrCNTs 2.69 3.02 5.47

AuPrCNTs 2.69 3.02 5.47

AuPrCNTs can be the commenced to the CN external and performance of the CN external and performance of the CNTs can be the CNT of the CNTs of the CNT AuPtCNTs

2.69 3.02 ²²²200 s, the (AuPt)₀₅-Ru/CNTs catalyst was reactive

(Au-Pt_O)--Ru/CNTs 21.4 4.82 ed by five consecutive CV cycles in 1 mol·L² KOII

ProC 6.51 1.25 solution, and followed by another CA test (Au,Pt_{s)},-RwCNTs 21.4 48.2 ed by five consecutive CV cycles in 1 mol -L¹ KOH

PPC: 0.51 1.25 ed by five consecutive CV cycles in 1 mol -L¹ KOH

solution, and followed by another CA test in a fresh 1

mol -L¹ (KOH PEC 0.51 1.25 solution, and followed by another CA test in a first 1
mol-L⁻¹ KOH electrolyte containing 1 mol-L⁻¹ chanol.
poisoning effect for EOR and the heterostructured CNTs could recover its original FOR activity. 28(8), 2201241 (6 of 10)
related to the amorphous-like state of AuPt in the
heterostructured $(AuPt)_{0.5}$ -Ru.
We have further studied the catalytic activity and
durability of the $(AuPt)_{0.5}$ -Ru/CNTs by CA experiments
at 0. 28(8), 2201241 (6 of 10)

related to the amorphous-like state of AuPt in the

heterostructured (AuPt)_{0.5}-Ru.

We have further studied the catalytic activity and

durability of the (AuPt)_{0.5}-Ru/CNTs by CA experiments
 (8), 2201241 (6 of 10)
ated to the amorphous-like state of AuPt in the
terostructured (AuPt)_{0.5}-Ru.
We have further studied the catalytic activity and
rability of the (AuPt)_{0.5}-Ru/CNTs by CA experiments
0.7 V (vs. RHE 28(8), 2201241 (6 of 10)

related to the amorphous-like state of AuPt in the

heterostructured $(AuPt)_{0.5}$ -Ru.

We have further studied the catalytic activity and

durability of the $(AuPt)_{0.5}$ -Ru/CNTs by CA experiments
 28(8), 2201241 (6 of 10)

related to the amorphous-like state of AuPt in the

heterostructured $(AuPt)_{0s}$ -Ru.

We have further studied the catalytic activity and

durability of the $(AuPt)_{0s}$ -Ru/CNTs by CA experiments

at 28(8), 2201241 (6 of 10)

related to the amorphous-like state of AuPt in the

heterostructured $(AuPt)_{0.5}$ -Ru.

We have further studied the catalytic activity and

durability of the $(AuPt)_{0.5}$ -Ru/CNTs by CA experiments
 28(8), 2201241 (6 of 10)

related to the amorphous-like state of AuPt in the

heterostructured $(AuPt)_{0.5}$ -Ru.

We have further studied the catalytic activity and

durability of the (AuPt)_{0.5}-Ru/CNTs by CA experiments
 28(8), 2201241 (6 of 10)

related to the amorphous-like state of AuPt in the

heterostructured $(AuPt)_{0.5}$ -Ru.

We have further studied the catalytic activity and

durability of the $(AuPt)_{0.5}$ -Ru/CNTs by CA experiments
 ed by five consecutive CV cycles in $1 \text{ mol} \cdot L^{-1}$ KOH 28(8), 2201241 (6 of 10)
related to the amorphous-like state of AuPt in the
heterostructured $(AuPt)_{0.5}$ -Ru.
We have further studied the catalytic activity and
durability of the $(AuPt)_{0.5}$ -Ru/CNTs by CA experiments
at 0. $mol \cdot L^{-1} KOH$ electrolyte containing 1 mol $\cdot L^{-1}$ ethanol. 2201241 (6 of 10)

1 to the amorphous-like state of AuPt in the

structured $(AuPt)_{0.5}$ -Ru.

have further studied the catalytic activity and

lity of the $(AuPt)_{0.5}$ -Ru/CNTs by CA experiments

V (vs. RHE), and the results 28(8), 2201241 (6 of 10)

related to the amorphous-like state of AuPt in the

heterostructured (AuPt)_{0.5}-Ru/CNTs by CA experiments

at 0.7 V (vs. RHE), and the results are presented in

Figure 3(d). After each chronoamp 28(8), 2201241 (6 of 10)

related to the amorphous-like state of AuPt in the

heterostructured $(AuPt)_{0s}$ -Ru.

We have further studied the catalytic activity and

durability of the $(AuPt)_{0s}$ -Ru/CNTs by CA experiments

at 28(8), 2201241 (6 of 10)

related to the amorphous-like state of AuPt in the

heterostructured $(AuPt)_{0s}$ -Ru.

We have further studied the catalytic activity and

durability of the $(AuPt)_{0s}$ -Ru/CNTs by CA experiments

at 28(8), 2201241 (6 of 10)

related to the amorphous-like state of AuPt in the

heterostructured $(AuPt)_{0a}$ -Ru.

We have further studied the catalytic activity and

durability of the $(AuPt)_{0a}$ -Ru/CNTs by CA experiments

at 28(8), 2201241 (6 of 10)

related to the amorphous-like state of AuPt in the

heterostructured $(AuPt)_{0s}$ -Ru.

We have further studied the catalytic activity and

durability of the $(AuPt)_{0s}$ -Ru/CNTs by CA experiments

at 28(8), 2201241 (6 of 10)

related to the amorphous-like state of AuPt in the

heterostructured $(AuPt)_{0a}$ -Ru.

We have further studied the catalytic activity and

durability of the $(AuPt)_{0a}$ -Ru/CNTs by CA experiments

at related to the amorphous-like state of AuPt in the
heterostructured $(AuPt)_{0a}$ -Ru.
We have further studied the catalytic activity and
durability of the $(AuPt)_{0a}$ -Ru/CNTs by CA experiments
at 0.7 V (vs. RHE), and the resu heterostructured $(AuP)_{0s}Ru$.
We have further studied the catalytic activity and
durability of the $(AuP)_{0s}Ru/CNTs$ by CA experiments
at 0.7 V (vs. RHE), and the results are presented in
Figure 3(d). After each chronoampe We have further studied the catalytic activity and
durability of the (AuPt)_{0s}-Ru/CNTs by CA experiments
at 0.7 V (vs. RHE), and the results are presented in
Figure 3(d). After each chronoamperometric test for
1200 s, th durability of the (AuPt)_{0s}-Ru/CNTs by CA experiments
at 0.7 V (vs. RHE), and the results are presented in
Figure 3(d). After each chronoamperometric test for
1200 s, the (AuPt)_{0.5}-Ru/CNTs catalyst was reactivat-
ed by at 0.7 V (vs. RHE), and the results are presented in Figure 3(d). After each chronoamperometric test for 1200 s, the (AuPt)_{0.5}-Ru/CNTs catalyst was reactivated by five consecutive CV cycles in 1 mol · L⁻¹ KOH solution gure 3(d). After each chronoamperometric test for 00 s, the $(AuPt)_{0x}Rw/CNTs$ catalyst was reactivat-
by five consecutive CV cycles in 1 mol·L¹ KOH
lution, and followed by another CA test in a fresh 1
l·L⁻¹ KOH electro 1200 s, the (AuPt)_{0.5}-Ru/CNTs catalyst was reactivated by five consecutive CV cycles in 1 mol \cdot L⁻¹ KOH solution, and followed by another CA test in a fresh 1 mol \cdot L⁻¹ KOH electrolyte containing 1 mol \cdot L ed by five consecutive CV cycles in 1 mol \cdot L⁻¹ KOH
solution, and followed by another CA test in a fresh 1
mol \cdot L⁻¹ KOH electrolyte containing 1 mol \cdot L⁻¹ ethanol.
More impressively, after reactivation, th solution, and followed by another CA test in a fresh 1
mol·L¹KOH electrolyte containing 1 mol·L¹ ethanol.
More impressively, after reactivation, the $(AuPt)_{us}-Ru$ /
CNTs could recover its original EOR activity. After
11 c \mathcal{U}_b ratio \mathbf{u}_a and \mathbf{u}_b of the $(\mathbf{A}\mathbf{u}_1\mathbf{u}_b)^T$ $\frac{dE}{dt} = \frac{dE}{dt} \left(\frac{dE}{dt} \right) \left(\frac{d$ $\begin{array}{rcl}\n & & \text{#Lé} \text{#U.} \text{ Electronic} & \text{#U.} \text{Electronic} \text{#U.} \text{ (a) } 2022, 28(8), 2201241 \text{ (6 of 10)}\\ \n \text{Table 1 Comparison in the activity of ethanol oxidation for} & & \text{related to the amorphous-like state of AuPt in the heterostructure (AuPH)_0-P.\text{R}u.}\\ \n & & \text{the AuPt/CNYs, (AuPH)_0-P.\text{W/CNYs}} & & \text{heterostructure (AuPH)_0-P.\text{R}u.}\\ \n & & \text{Catalyst} & & \text{the H.} \text{ (a) } 2$ $\frac{dE\#C(LElectrochem.) 2022, 28(8), 2201241 (6 of 10)
\n**the** AulP/CNTs (AulP)_W-Ru/CNTs and RulP/Au/CNTs
\ncalylsts, as well as PtC catalyst
\ncallyst
\n $I_{\text{peak}}\Lambda$ -mgg_W¹ $J_{\text{peak}}\Lambda$ ratio
\n $I_{\text{peak}}\Lambda$ -mgg_W² $J_{\text{peak}}\Lambda$ ratio
\n $I_{\text{peak}}\Lambda$ -mgg_W$ $\frac{dE}{dt}$ + Electrochem.) 2022, 28(8), 2201241 (6 of 10)
 ELECT COMPARENTS in the activity of ethanol oxidation for

the AuPt/CNTs, (AuPt_{)av}-RuCNTs and RuPt4wCNTs

catalyst, as well as Pt/C catalyst.
 ELECT CAUPT

Figure 5 In-situ FTIR spectra of EOR on the (AuPt)_{0.5}-Ru/CNTs catalyst at the 1st run in 1 mol \cdot L⁻¹ KOH containing 1 mol \cdot L⁻¹ EtOH

mol·L⁻¹ ethanol and 1.0 mol·L⁻¹ KOH solution recordions $(CH_3COO)^{[24]}$. Note that at high pH environment, Example the single product (CO) and a state of the single product (CO)²⁴¹. Note that in the best HFR performance among these samples. The single with the band of 1418 cm¹ from acetat⁶³³. The control of the band of 1 (CO_3^2) , which displays a band at 1390 cm⁻¹ and over-2. The spectra of ethanol oxidation in 1.0 COD stretching vibrations corresponding to formation of the spectra of ethanol oxidation in 1.0 COO stretching vibrations corresponding to formate the strain in The spectra of et Figure 5 *h*₃₁₈₀ 1380 1380 1380 1390 1390 1390 2300 2300 1880 1680 1420 1418 211

Figure 5 *h*₃₁₈₀ 1180 Wavenumber (cm⁺)

Figure 5 *h*₃₁₈₀ i¹¹⁸ Repectra of echanol oxidation in 1.0 COO stretching vibrations corr

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 EXERCISE AND CONSTRANCE AUTORS (SURVENTS)
and $2200 - 2000 - 1800 - 1400$
with the 1st run in 1 mol·L¹ KOH containing 1 mol·L¹ EtOH
COO⁻ stretching vibrations corresponding to formate
species (HCOO) were observed at AuPt/CNTs and Pt/C, as shown in Figure 6(a-c). It is
clearly observed that the text like of the set of the set of the set of the species (HCOO) were observed at 1340 cm⁻¹²⁶. The
IR band at 1044 cm⁻¹ belonged to C₂H **Example 12.1**
 COVERTS
 COVERT 2200 2200 1800 1800 1600 1400

Wavenumber (cm⁺)

yst at the 1st run in 1 mol·L⁻¹ KOH containing 1 mol·L⁻¹ EtOH

COO⁻ stretching vibrations corresponding to formate

species (HCOO) were observed at 1340 cm⁻¹²⁶. T

 $(AuPt)_{0.5}-Ru/CNTs$ only required an overpotential the RuO₂ at the low current density (< 5 mA · cm⁻²) and

(η_{10}) of 30 mV, which is 80, 110 and 10 mV lower high current density (> 60 mA · cm⁻²). Tafel slope of

t $#E\# (J. Electrochem.)$ (AuPt)_{0.5}-Ru/CNTs only required an overpotential the RuO₂ at the low current density (< 5 mA·cm²) and (η_{10}) of 30 mV, which is 80, 110 and 10 mV lower high current density (> 60 mA·cm²). Tafel the AuPt)_{0s}-Ru/CNTs only required an overpotential the RuO₂ at the low current density (< 5 mA·cm²) and (η_{10}) of 30 mV, which is 80, 110 and 10 mV lower high current density (< 60 mA·cm²). Tafel slope of $(\eta_{1$ $\frac{d}{dt}\frac{d}{dt}\left(\int_{0}^{2\pi}F(t) \cdot g(t)dt\right)$

(AuPt)_{0.5}-Ru/CNTs only required an overpotential the RuO₂ at the low current density (< 5 mA · cm²) and

(η_{10}) of 30 mV, which is 80, 110 and 10 mV lower high current den $\frac{\text{H}(E\#(J. Electrochem.) 2022, 28(8), 2201241 (8 of 10)}{\text{(AuPt)}_{0.5} \cdot \text{Ru/CNTs}}$ (AuPt)_{0.5}-Ru/CNTs only required an overpotential the RuO₂ at the low current density (< 5 mA·cm²) and (η_{10}) of 30 mV, which is 80, 110 and 1 **EVALUATE 15 (Example 1902)** 28(8), 2201241 (8 of 10)

(AuPt)₀-Ru/CNTs only required an overpotential the RuO₂ at the low current density (<5 mA·cm²) and

(η_{m}) of 30 mV, which is 80, 110 and 10 mV lower high **EVACATIVE 16** meta determinaming steps (*L. Blectrochem.*) 2022, 28(8), 2201241 (8 of 10)

(AuPt)_{0.5}-Ru/CNTs only required an overpotential the RuO₂ at the low current density (<5 mA·cm³) and

(η_{10}) of 30 mV, **manually, Although the AuPt (AuPt)** and AuPtCNTs and AuPtCNTs and AuPtCNTs and AuPtCNTs and AuPtCNTs, and a computed the RuO₂ at the low current density (≤ 5 mA \cdot cm³) and (η_m) of 30 mV, which is 80, 110 and 1 $(ADP)_0$, Ru/CNTs only required an overpotential the RuO₂ at the low current density (≤ 5 mA · cm²) and (η_0) of 30 mV, which is 80, 110 and 10 mV lower high current density (> 60 mA · cm²). Tafel slope of th **EVALUATE ALTERT THE SET ALTERT CONDUCTERT ALTERT CONDUCTED (SO THE READ ALTERT CONDUCTED (ALTERT CONDUCTED THE READ ALTERT CONDUCTED THE READ ON THE READ ON THE READ ON THE PROPORT CONDUCTED AND THE PUCC. THE CAUPURICATE rovsky step for the AuPtackies** of the RuO₂ and PuPCNTs of the RuO₂ and AuPt_O and C(n_a) of 30 mV, which is 80, 110 and 10 mV lower high current density ($>$ 60 mA \cdot cm⁵). Tafel slope of the AuPtAuCNTs, AuPtCN Volmer step for the AuPtRu/CNTs and AuPt/CNTs. **IDENTAL Electrochem.**) 2022, 28(8), 2201241 (8 of 10)

IDENta-FWCNTs only required an overpotential the RuO₂ at the low current density (<5 mA·cm⁻) and

g) of 30 mV, which is 80, 110 and 10 mV lower

that water densi $\frac{d}{dt}$ ($\frac{d}{dt}$) ($\frac{d}{$

It is usually believed that water dissociation kinet-

ics is shown on Pt than the transition metals with \sim CNTs showed superior EOR performance, and the

ics is shown on Pt than the transition metals with \sim CNTs sh ies is shower on Pt than the transition metals with CNTs showed superior EOR performance, and the Thure of elicient d-electrons¹²¹, such as Ruy, Co and Ni, mass activity of Pt toward EOR was as high as 21.4 Thus, the in more deficient d-electrons^{pri}, such as Ru, Co and Ni. mass activity of Pt toward EOR was as high as 21.4
Thus, the introduction of Ru into AuPt alloy could Armg¹, extremely higher than those of the previously
promote Thus, the introduction of Ru into AuPt alloy could

A-mg⁻¹, extremely higher than those

promote water dissociation on the Ru site, while hy-

reported catalysts in the literature, as

drogen desorption through the Heyr promote water dissociation on the Ru site, while hy-

oreported eatalysts in the literature, as well as those of

drog describes althous the marking mixed Au-marking Au-Markin Au-marking and the marking mixed Au-marking i occur on the Pt site^[38]. It was found that the RuAuPt⁷ The *in-situ* FTIR spectroscopic study identified the CNTs exhibited hetter alkaline HFR performance wwith Romance is the and 1450 orn³ and AuPtCNTs. This sugg CNTs exhibited better alkaline HER performance

two IR bands at 1550 cm⁻ and 1415 cm⁻, at

then the AuPt⁻CNTs. This suggests that the water dis-

solution dynamics are sufficiently improved upon

the formation of th than the AuPt/CNTs. This suggests that the water dis-

solution dynamics: are sampled the symmetric and symmetric C-O bonds of accide

the formation of the AuPt-Ru heterostructure. Usual

the formation of the AuPt-Ru hete sociation dynamics are sufficiently improved upon

tons (CH,COO), respectively, and the IR band at 1390

the formation of the AuPtRu heterostructure. Usual-

cm¹ from carbons et (CO_C³). The (AuPtP_{is-}Ru/CNTs

CMTs

the formation of the AuPI-Ru heterostructure. Usual-

Unif from carbonate (CO_C). The (AuPI_{)ax}-Ru/CNTs

ly, the doping R Ru into AuPI lattice could induce

also exhibited the excellent cleared recelent cleared as the
 Iy, the doping of Ru into AuPt lattice could induce

solution to excellent electrochemical stability

compressive strain and downshift of the d-band of Pt.

Multe the formation of heterostrotured AuPt with

denotition of compressive strain and downshift of the d-band of Pt. and long-term durability in ethanol oxidation. The White the formation of hetercostructured AuPt with describention of the callysts was accompanied by the amorphous Ru While the formation of heterostructured AuPt with

and contribution of the etathysis was accompanied by the

amorphous Ru can well maints the original d-band is strong adsorption of water molecules.

In EOR activity, Conc amorphous Ru can well maintain the original d-band

or RuPt and its strong adsorption of water molecules.

The in EOR activity, Concurrently, the (AuPt)_{0.5}-Ru/

Most importantly, the amorphous Ru may behave as

CNTs als

28(8), 2201241 (8 of 10)
the RuO₂ at the low current density (< 5 mA·cm⁻²) and
high current density (> 60 mA·cm⁻²). Tafel slope of
the (AuPt)₀₅-Ru/CNTs (114 mV·dec⁻¹) was also much
lower than those of the other 28(8), 2201241 (8 of 10)
the RuO₂ at the low current density (< 5 mA · cm⁻²) and
high current density (> 60 mA · cm⁻²). Tafel slope of
the (AuPt)_{0.5}-Ru/CNTs (114 mV · dec⁻¹) was also much
lower than those of the 28(8), 2201241 (8 of 10)
the RuO₂ at the low current density (\leq 5 mA · cm²) and
high current density ($>$ 60 mA · cm²). Tafel slope of
the (AuPt)_{0.5}-Ru/CNTs (114 mV · dec⁻¹) was also much
lower than those of 28(8), 2201241 (8 of 10)

the RuO₂ at the low current density (< 5 mA · cm²) and

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the RuO₂ at the low current density (< 5 mA · cm⁻²) and
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RuO₂ at the low current density (< 5 mA · cm⁻²) and

gh current density (> 60 mA · cm⁻²). Tafel slope of
 $\left(\frac{A u P t_{0a} - R u}{CNTs} \right)$ (114 mV · dec⁻¹) was also much

wer than those of the ot $\text{H}(k\#(J. \text{Electrochem.}) 2022, 28(8), 2201241 (8 of 10))$ red an overpotential the RuO₂ at the low current density (< 5 mA·cm⁻²) and

10 and 10 mV lower high current density (> 60 mA·cm⁻²). Tafel slope of

Ts, AuPt/CNTs, an

4 Conclusions

the $\frac{\ln\{t/2^k\}(f, Keemchem), 2022,28(8), 2201241 (8 of 10)$

(AuPh_{3e}-Ru/CNTs only required an overpotential the RuO₂ at the low current density (≤ 5 mA - cm²) and

(η_{00}) of 30 mV, which is 80, 110 and 10 mV lower h (AuPt₎₃-Ru/CNTs only required on overpotential the RuQ_a R_u at he low current density (< 5 mA - cm³) and

(η_{m}) of 30 mV, which is 80, 110 and 10 mV lower high current density (>60 mA - cm³). Tafel slo (AuPt)₃₀-Ru/CNTs only required an overpotential

(A_D) of 30 mV, which is 80, 110 and 10 mV lower high current density ($>$ 6 mA - cm³) and

($\eta_{\rm B}$) of 30 mV, which is 80, 110 and 10 mV lower high current density (η_{B}) of 30 mV, which is 80, 110 and 10 mV lower

then these of the AuPhRuCKTIs, and the (AuPENTS, and the (AuPENTS)₀, Redef (MappRuCKTIS (114 mV)-dec³ (was also much

then those of the other based and the (MPD than those of the AuPtRu/CNTs, AuPt/CNTs, and the (AuPt_{Da}-Ru/CNTs (114 mV·dec⁺) was also much

Pc/C, respectively. The (AuPt_{Da}-Ru/CNTs catalytic lover than those of the other catalytis [Figure 6(f)),

Pc/Eyrectively PVC, respectively. The $(AuP)_{6}$ -RwCNTs eatalyst

elvote than those of the other catalysts (Figure 6(1),

schilded the fastest alkaline HER kineties, as demon-

stated by the smallest Tafel slope in Figure 6(c). **4 Conclu** exhibited the fastest alkaline HFR kinetics, as demon-
stragesting a very rapid OER reaction rate.
strated by the smallest Tafel slope in Figure 6 (c), **4 Conclusions**
namely, 45 mV -dec' for the (AuPt)_N-Ru/CNTs, 163 strated by the smallest Tafel slope in Figure 6(c), **4 Conclusions**
namely, 48 mV·dec¹ for the (AuPh_{io}-RunchYirs, 163 m summary, this work has demonstrated the sue-
nmV·dec¹ for the AuPHRuCCNTs, 203 mV·dec¹ for th namely, 45 mV -dcc⁺ for the (Δu Pt)_{0x}-Ru/CNTs, 163

in summary, this work has demonstrated the suc-

mV-dcc⁺ for the AuPt-Ru/CNTs, 203 mV -dcc⁺ for the cosstil synthesis of leass-

and Hetrostructure. AuPt/CNTs mV \cdot dce⁺ for the AuPtRu/CNTs, 203 mV \cdot dce⁺ for the cossful synthesis of less crystallized and heterostrue-
AuPr/CNTs and 81 mV \cdot dec⁺ for PtC. These Tafel

subgrCNTs and PtC, theil tured (AuPh₃-Ru/CNTs and AuPt/CNTs and 81 mV - dee" for Pt/C. These Tafel tured $(AuP)_{\text{Ar}}$ -Ru nanomaterials supported on CNTs
slops indicate that he rate determining step is Hey-
sequential chand rotated. The reduced
rowsky step for the (AuPh₂ slopes indicate that the rate determining step is Hey-
by sequential ethanol reduction method. The reduced
volmer step for the (AuPh_{oc}-Ru/CNT)s and $Pv(C$, while
experime state of AuPt alloy and formation of het-
Volmer rovsky step for the (AuP)_M-RwCNTs and PrC, while crystalline state of AuPt alloy and formation of het-
Volmer step for the AdPRwCCNTs and AuPu²CNTs. erestricture were confirmed by XRD data and ele-
It is usually belie Volmer step for the AuPtRu/CNTs and AuPt/CNTs.

It is usually believed that water dissociation kinet-

it is usually believed that water dissociation inclusing implication inclusing

it is slower on Pt than the transition The HER performance two IR bands at 1550 cm⁻¹ and 1415 cm⁻¹, ascribing to

ests that the water dis-

the asymmetric and symmetric C-D bonds of accetate

the transformation ions (CH_CCOO), respectively, and the IR ban 28(8), 2201241 (8 of 10)
the RuO₂ at the low current density (\leq 5 mA · cm⁻²) and
high current density ($>$ 60 mA · cm⁻²). Tafel slope of
the (AuPt)_{0.5}-Ru/CNTs (114 mV · dec¹) was also much
lower than those o 28(8), 2201241 (8 of 10)
the RuO₂ at the low current density (< 5 mA · cm²) and
high current density (> 60 mA · cm²). Tafel slope of
the (AuPt)_{0.5}-Ru/CNTs (114 mV · dec¹) was also much
lower than those of the ot 28(8), 2201241 (8 of 10)

the RuO₂ at the low current density (< 5 mA·cm²) and

high current density (> 60 mA·cm²). Tafel slope of

the (AuPt)_{0a}-Ru/CNTs (114 mV·dec⁺) was also much

lower than those of the other 28(8), 2201241 (8 of 10)
the RuO₂ at the low current density (< 5 mA·cm²) and
high current density (> 60 mA·cm²). Tafel slope of
the (AuPt)_{0a}-Ru/CNTs (114 mV·dec⁻) was also much
lower than those of the other cat 28(8), 2201241 (8 of 10)
the RuO₂ at the low current density (< 5 mA·cm²) and
high current density (> 60 mA·cm²). Tafel slope of
the (AuPt)₀₃-Ru/CNTs (114 mV·dec⁻¹) was also much
lower than those of the other ca 28(8), 2201241 (8 of 10)

the RuO₂ at the low current density (< 5 mA · cm⁻³) and

high current density (> 60 mA · cm⁻²). Tafel slope of

the (AuPt)_{0.5}-Ru/CNTs (114 mV · dec⁻¹) was also much

lower than those of 28(8), 2201241 (8 of 10)
the RuO₂ at the low current density (< 5 mA · cm²) and
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the (AuPt)₀₃-Ru/CNTs (114 mV · dec⁻¹) was also much
lower than those of the ot 28(8), 2201241 (8 of 10)

the RuO₂ at the low current density (\leq 5 mA · cm²) and

high current density ($>$ 60 mA · cm²). Tafel slope of

the ($AuPt)_{0s}$ -Ru/CNTs (114 mV · dec⁻¹) was also much

lower than thos **EQUALTE AS TO THE CONDENDICATE (SOLUTE THE ACT AT AT AND ADDEDITED THE AND CONDUST THE AND THE AND THE SUPREM (AUPT)** α -RWCNTs (114 mV·dec⁻¹) was also much lower than those of the other catalysts (Figure 6(f)), sug the RuO₂ at the low current density (< 5 mA · cm⁻²) and
high current density (> 60 mA · cm⁻²). Tafel slope of
the (AuPt)_{0s}-Ru/CNTs (114 mV · dec⁻¹) was also much
lower than those of the other catalysts (Figure 6 high current density (> 60 mA · cm²). Tafel slope of
the (AuPt)₀₃-Ru/CNTs (114 mV · dec⁻¹) was also much
lower than those of the other catalysts (Figure 6(f)),
suggesting a very rapid OER reaction rate.
4 Conclusio the $(AuPt)_{0.3}$ -Ru/CNTs (114 mV·dec⁻¹) was also much
lower than those of the other catalysts (Figure 6(f)),
suggesting a very rapid OER reaction rate.
4 Conclusions
In summary, this work has demonstrated the suc-
ces lower than those of the other catalysts (Figure 6(f)),
suggesting a very rapid OER reaction rate.
4 Conclusions
In summary, this work has demonstrated the suc-
cessful synthesis of less crystallized and heterostruc-
tur suggesting a very rapid OER reaction rate.
 4 Conclusions

In summary, this work has demonstrated the suc-

cessful synthesis of less crystallized and heterostruc-

tured $(AuPt)_{0.5}$ -Ru nanomaterials supported on CNTs
 4 Conclusions
In summary, this work has demonstrated the suc-
cessful synthesis of less crystallized and heterostruc-
tured $(AuPt)_{0s}$ -Ru nanomaterials supported on CNTs
by sequential ethanol reduction method. The reduc **ions**

, this work has demonstrated the suc-

is of less crystallized and heterostruc-

Ru nanomaterials supported on CNTs

thanol reduction method. The reduced

e of AuPt alloy and formation of het-

ere confirmed by XR In summary, this work has demonstrated the suc-
cessful synthesis of less crystallized and heterostruc-
tured $(AuPt)_{0.5}$ -Ru nanomaterials supported on CNTs
by sequential ethanol reduction method. The reduced
crystalline has demonstrated the suc-
rystallized and heterostruc-
aterials supported on CNTs
action method. The reduced
alloy and formation of het-
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PF-TEM. The (AuPt)_{0.5}-Ru/
iOR performance, and the
H EOR cessful synthesis of less crystallized and heterostrue-
tured $(AuPt)_{a5}$ -Ru nanomaterials supported on CNTs
by sequential ethanol reduction method. The reduced
crystalline state of AuPt alloy and formation of het-
erostr tured (AuPt)_{0s}-Ru nanomaterials supported on CNTs
by sequential ethanol reduction method. The reduced
crystalline state of AuPt alloy and formation of het-
reostructure were confirmed by XRD data and ele-
mental mapping by sequential ethanol reduction method. The reduced
crystalline state of AuPt alloy and formation of het-
erostructure were confirmed by XRD data and ele-
mental mapping in HAADF-TEM. The $(AuPt)_{0.5}$ -Ru/
CNTs showed super cystalline state of AuPt alloy and formation of het-
erostructure were confirmed by XRD data and ele-
mental mapping in HAADF-TEM. The $(AuPt)_{0.5}$ -Ru/
CNTs showed superior EOR performance, and the
mass activity of Pt towa erostructure were confirmed by XRD data and ele-
mental mapping in HAADF-TEM. The $(AuPt)_{0.5}$ -Ru/
CNTs showed superior EOR performance, and the
mass activity of Pt toward EOR was as high as 21.4
A - mg⁻¹, extremely high mental mapping in HAADF-TEM. The $(AuPt)_{0.5}Ru$
CNTs showed superior EOR performance, and the
mass activity of Pt toward EOR was as high as 21.4
A -mg⁻¹, extremely higher than those of the previously
reported catalysts in CNTs showed superior EOR performance, and the
mass activity of Pt toward EOR was as high as 21.4
A - mg⁻¹, extremely higher than those of the previously
reported catalysts in the literature, as well as those of
the unif mass activity of Pt toward EOR was as high as 21.4
A-mg⁻¹, extremely higher than those of the previously
reported catalysts in the literature, as well as those of
the uniformly mixed AuPt and RuAuPt nanoparticles.
The A - mg⁻¹, extremely higher than those of the previously
reported catalysts in the literature, as well as those of
the uniformly mixed AuPt and RuAuPt nanoparticles.
The *in-situ* FTIR spectroscopic study identified the
 is uniformly mixed AuPt and RuAuPt nanoparticles.

te *in-situ* FTIR spectroscopic study identified the o IR bands at 1550 cm⁻¹ and 1415 cm⁻¹, ascribing to a symmetric and symmetric C-O bonds of acetate is (CH₃COO), of R bands at 1550 cm⁻¹ and 1415 cm⁻¹, ascribing to asymmetric and symmetric C-O bonds of acetate is (CH₃COO), respectively, and the IR band at 1390 i⁻¹ from carbonate (CO₃²). The (AuPt)_{0.5}-Ru/CNTs o exhibit the asymmetric and symmetric C-O bonds of acetate
ions (CH₃COO'), respectively, and the IR band at 1390
cm⁻¹ from carbonate (CO₃²). The (AuPt)_{0.5}-Ru/CNTs
also exhibited the excellent electrochemical stability
an ions (CH₃COO), respectively, and the IR band at 1390
cm⁻¹ from carbonate (CO₃²). The (AuPt)_{0.5}-Ru/CNTs
also exhibited the excellent electrochemical stability
and long-term durability in ethanol oxidation. The
de and complete ant extent the contour and dong-term durability in ethanol oxidation. The deactivation of the catalysts was accompanied by the loss of Ru contents, implying that Ru plays a crucial role in EOR activity. Concur follow-term durabinty in ethable of Madion. The
citvation of the catalysts was accompanied by the
of Ru contents, implying that Ru plays a crucial
in EOR activity. Concurrently, the $(AuPt)_{0.5}Ru'$
Ts also displayed the e cityation of the catalysis was accompanied by the
of Ru contents, implying that Ru plays a crucial
in EOR activity. Concurrently, the $(AuPt)_{0.5}Ru$
Ts also displayed the excellent HER and OER ac-
ties in alkaline media, w is of Ru contents, implying that Ru plays a crucial

in EOR activity. Concurrently, the $(AuPt)_{0.3}$ -Ru/

Ts also displayed the excellent HER and OER ac-

eines in alkaline media, which was ascribed to the

emble and strai

Notes:

Acknowledgements:

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trimetalliie PfRICu cubic mnoboxes for ethanol electro 251-261. **EGALUSE 16** (*Electrochen*.) 2022, 28(8), 2201241 (9 of 10)

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tion of ethanol on a ternary Au(core)-Pt (8), 2201241 (9 of 10)

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低结晶度 AuPt-Ru/CNTs 合金异质结作为 高效多功能电催化剂

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摘要: 催化剂的活性与其结构紧密相关, 研究催化剂的构效关系以及可控合成高效电催化剂, 并探究其催化机 制,一直是科学研究的核心。贵金属铂是优异的电解水析氢的催化剂,同时也是直接醇燃料电池阳极氧化的良好 催化剂,而贵金属钌是优异的电解水析氧催化剂。这些与燃料电池及氢能相关的重要反应催化剂,可通过合成 Pt、Au 及 Ru 的合金催化剂, 通过应力效应、电子效应及团簇效应, 可有效提高金属催化剂的活性, 并实现多功 能电催化性能。本文报道了可控合成低结晶度的 AuPt-Ru 合金异质结,并通过元素扫描分析及 X 射线衍射分析确 认其结构。该催化剂表现出了非常优异的电催化氧化乙醇活性, 其归一化到 Pt 的质量活性达到了为 21.4 A·mg-lpt, 远远高于对照组样品 AuPt 及 RuAuPt 混合相催化剂及文献报道样品。催化剂同样表现出了非常好的乙 醇氧化稳定性,但是其活性的衰减与其 Ru 组分的流失紧密相关。我们同时通过电化学原位红外光谱,研究了该 催化剂乙醇氧化中间产物, 分析了其反应机理。该催化剂同样表现出了优异的碱性电解水析氢及析氧催化活性, 其析氢电流 10 mA窑cm-2 对应的过电位为 30 mV^袁 Tafel 斜率为 45 mV窑dec-1 其析氢电流 10 mA·cm² 对应的过电位为 30 mV, Tafel 斜率为 45 mV·dec⁻¹, 优于 AuPt及 RuPtAu 对照组样品。 该催化剂优异的电化学性能主要归结于其低结晶度和异质结及其伴随的应力效应及团簇效应。本报道提供了一 种可控合成具有异质结结构的金属合金催化剂,突出了其对实现多功能、高性能合金电催化剂的重要性。 关键词: 钌: 异质结: AuPt 合金: 乙醇电氧化: 电解水析氢: 电解水析氧