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# Advances of Phosphide Promoter Assisted Pt Based Catalyst for Electrooxidation of Methanol

Meng Li

Li-Gang Feng School of Chemistry and Chemical Engineering, Yangzhou University, Yangzhou, 225002, Jiangsu, China;, ligang.feng@yzu.edu.cn

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&\text{Advances of Phosphide Promoter Assisted Pt Based Catalyst for} &\text{Electrooxidation of Method} & \text{Methanol} & \text{Meng Li, Li-Gang Feng} & \text{Feng}^*\n\end{array}$  $\begin{array}{lll} &\text{\#} & \text{\#} \\ \text{\#} & \text{\#} & \text{\#} \\ \text{\textbf{DOI: }} 10.13208/j.\text{electrochem}. 2106211}\; \text{(1 of 12)} \end{array} \qquad \qquad \text{\textbf{Htp://electrochem.xml.edu.cn}} \\ \text{\textbf{phide Promoter Assisted Pt Based} } \text{Catalyst for} \\ \text{\textbf{Electrooxidation of Method}} & \text{\textbf{Method of Method}} \\ \text{Meng Li, Li-Gang Feng}^{*} & \text{\#} \\ \text{\#} & \text{\#} \\ \text{\#} & \text{\#} \\ \text{\#} & \text{\#} \\$ セルティル<br>
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10.13208/j.electrochem.210621<br> **Http://electrochem.xmu.edu.or**<br> **romoter Assisted Pt Based Catalyst for**<br> **oridation of Methanol**<br>
Meng Li, Li-Gang Feng<sup>\*</sup><br>
vering, Yangzhou Un  $\frac{1}{2}$  *L Electrochem.* 2022, 28(1), 2106211 (1 of 12)<br> **Eview]** DOI: 10.132085j-electrochem.210621<br> **Advances of Phosphide Promoter Assisted Pt Based Catalyst for<br>
<b>Electrooxidation of Methanol**<br>
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*hool of Chemistry and Chemical Engineering, Yangzhou University, Yangzhou, 225002, Jiangsu, China)*<br> **dract:** Transition metal phosphide (TMP), as an ideal catalytic promoter in methanol fuel oxidation, has received incr **Abstract:** Transition metal phosphide (TMP), as an ideal catalytic promoter in methanol fuel oxidation, has received increased<br>utention because of its multifirmctional active sites, tamble structure and composition, as w **A hatract:** Transition metal phosphide (TMP), as an ideal catalytic promoter in methanol fuel oxidation, has received increased<br>attention because of its multificancional active sites, tumble structure and composition, as **Abstract:** Transition metal phosphids (TMP), as an ideal catalytic promoter in methanol fuel oxidation, has received increased<br>internom because of its multiformediated active sines, tunable structure and composition, as attention because of its multifunctional active sizes, hundels arruce and composition, as well as unique physical and elementative is the matter of the matter is the summation because of the matter is the advantage of the properties and extinent muni-composition synegotic effect. Some and we been made for this can<br>be an energy and the research progresses of transition metal phosphides (TMPs) in the ansied electroxicalition of melthanol incl not encomple the example prompt and the polytom and the promptom and the promotion and their performance evaluation for methanol oxidation are reviewed. The promotion effect of TMFs has been firstly presented and the catal -Gang Feng<sup>\*</sup><br>
thow University, Yangzhou, 225002, Jiangsu, China)<br>
ic promoter in methanol fuel oxidation, has received increased<br>
re and composition, as well as unique physical and chemical<br>
vances have been made for thi **Example 12.**<br>
Consequence in methanol fuel oxidation, has received increased<br>
re promoter in methanol fuel oxidation, has received increased<br>
re and composition, as well as unique physical and chemical<br>
vances have been ic promoter in methanol fuel oxidation, has received increased<br>re and composition, as well as unique physical and chemical<br>vances have been made for this catalyst system recently. In the<br>(TMPs) in the assisted electrooxid ic promoter in methanol fuel oxidation, has received increased<br>re and composition, as well as unique physical and chemical<br>vances have been made for this catalyst system recently. In the<br>s (TMPs) in the assisted electroox ic promoter in methanol fuel oxidation, has received increased<br>re and composition, as well as unique physical and chemical<br>vances have been made for this catalyst system recently. In the<br>s (TMPs) in the assisted electroox  $\begin{tabular}{ll} \textbf{4e} & $\langle k \rangle$ & $\langle k \rangle$ \\ \hline \textbf{1} & \textbf{1} & \textbf{2} & \textbf{2$ **Exercise of Phosphide Promoter Assisted Pt Based Catalyst for<br>
Advances of Phosphide Promoter Assisted Pt Based Catalyst for<br>
Electrooxidation of Methanol<br>
Meng Li, Li-Gang Feng<sup>\*</sup><br>
(School of Chemistry and Chemical Engi Properties and Express and effects** and effects and the effect multi-composition syntential composition syntential multi-composition syntential composition syntems. The effect of the material composition of Methannol<br>
Me **Externe review and Fig. 2014**<br> **current reviews FE Current research propriate research propriate interaction of Methanol<br>
<b>Advances of Phosphide Promoter Assisted Pt Based Catalyst for**<br> **Electrooxidation of Methanol** *thermolenn*, 2022, 28(1), 2106211 (1 of 12)<br> **Ekview]** DOI: 10.132085, determokem, 2022, 28(1), 2106211 (1 of 12)<br> **Catalyst for**<br> **Catalyst for**<br> **Catalyst for**<br> **Catalyst for**<br> **Catalystication and the performance eval** *L Bectrochem*, 2022, 28(1), 2106211 (1 of 12)<br>
DOI: 10.13208/j.electrochem.210621<br> **Advances of Phosphide Promoter Assisted Pt Based Catalyst for<br>
Electrooxidation of Methanol<br>
Meng Li, Li-Gang Feng<sup>\*</sup><br>
(School of Chemis** functional catalytic mechanism. The problems and catalytic mechanism. The problems and challenges in the **Electrooxidation of Methanol**<br>
Meng Li, Li-Gang Feng<sup>\*</sup><br>
(School of Chemistry and Chemical Engineering, Yangzhou Uni Advances of Phosphide Promoter Assisted Pt Based Catalyst for<br>Electrooxidation of Methanol<br>Merginian Methanol<br>Methanol<br>(School of Chemistry and Chemical Engineering, Yangshou University, Yangshou, 225002, Jiangsu, China)<br> Advances of Phosphide Promoter Assisted Pt Based Catalyst for<br>
Electrooxidation of Methanol<br>
Meng Li, Li-Gang Feng<sup>\*</sup><br>
(School of Chemistry and Chemical Engineering, Yangehou University, Yangehou, 225002, *Eangsu*, China)<br> **Example 11 Conferent Conference C** 

unsafe problems involving the application of hydro-<br>
EMPCs systems with a power output range of 25 ~<br>
gen fuel; the advantages of small size, high theoreti-<br>
2000 W for portable applications have been done by<br>
San's resea Direct methanol fitel cells (DMFCs) that use liq.<br>
and Smart Fuel Cells (Germany) with the system<br>
and Smart Fuel Cells (Germany) with the system<br>
conversion technique hecause they can overcome the<br>
manying charge ranging hanol as fuel are kind of promising energy<br>
and Smart Fuel Cells (Germany) with the s<br>
magnig from 25 to 1000 W, ir nearwhile, a section with a power coupler<br>
the advantages of small size, high theoretic are all to Wicky **1 Introduction** The initial commercialization of DFMCs has been been firstly presented and the catalystystems based on the different metal centers of TMPs are then mainly discussed. It is concluded<br>that the TMPs are the samply pronons metalanon consider on through the electoric effect ed that the TMPs can greatly promote methanol oxidation through the electronic effect and the oxypthilic property bosed on the bi-<br>
functional early in emetasion. The problems and challenges in methanol fatle oxidation by functional eatalytic mechanism. The problems and challenges in methanol fuel oxidation by using TMFs are also described at the developed and the direction direction being paid to the precise cather direction of the fuel c end with the attention being paid to the precise catalyst design. The catalytic mechanism probing and application of the fuel cells<br>device are proposed. The current effort might be helpful to the community for novel catal device are proposed. The current effort might be helpful to the community for novel catalyst system design and fabrication.<br> **Key words:** cansition metal phosphide; methanol oxidation reaction; promoter; electrocatalysis<br> **Example 19 Example 19 Example 19 Example 19 Example 19 CHE CONFIGS CHEC INTERVIER INTERVIER CONFIGERAT CONFIGS CHECK CERTIFY EXAMPLE 19 EXAMPLE 19 EXAMPLE 19 EXAMPLE 19 EXAMPLE 19 EXAMPLE 19 1 Introduction**<br>
The initial commercialization of DFMs has been<br>
Direct methanol fiel cells (DMFCs) that use liq-<br>
iried by some companies like UltraCell (United States)<br>
uid methanol as fuel are kind of promising energy **1 Introduction**<br>
The initial commercialization of DFMCs has been<br>
Direct methanol fitel cells (DMFCs) that use  $\frac{1}{2}$  ried by some companies like UltraCell (United States)<br>
uid methanol as fuel are kind of promising e more challenging for their commercial applications<sup>[5,6]</sup>. the noble metal active sites and carbon support rere and composition, as well as unique physical and chemical<br>vances have been made for this catalyst system recently. In the<br>(TMPs) in the assisted electrooxidation of methanol including<br>nol oxidation are reviewed. The pro by<br>ances have been made for this catalyst system recently. In the<br>
(TMPs) in the assisted electrooxidation of methanol including<br>
nol oxidation are reviewed. The promotion effect of TMPs has<br>
metal centers of TMPs are the s (TMPs) in the assisted electrooxidation of methanol including<br>nol oxidation are reviewed. The promotion effect of TMPs has<br>metal centers of TMPs are then mainly discussed. It is conclud-<br>e electronic effect and the oxyph not oxidation are reviewed. The promotion effect of TMPs has<br>metal centers of TMPs are then mainly discussed. It is conclud-<br>e electronic effect and the oxyphilic property based on the bi-<br>thanol fuel oxidation by using TM metal centers of TMPs are then mainly discussed. It is conclude electronic effect and the oxyphilic property based on the bi-<br>thanol fuel oxidation by using TMPs are also described at the catalytic mechanism probing and a is electronic effect and the oxyphilic property based on the bi-<br>thanol fuel oxidation by using TMPs are also described at the<br>catalytic mechanism probing and application of the fuel cells<br>unity for novel catalyst system thanol fitel oxidation by using TMPs are also described at the catalytic mechanism probing and application of the fuel cells unity for novel catalyst system design and fabrication.<br>
The initial commercialization of DFMCs calalytic mechanism probing and application of the fuel cells<br>unity for novel catalyst system design and fabrication.<br>The initial commercialization of DFMCs has been<br>tried by some companies like UltraCell (United States)<br> the point of novel calaryst system design and faoteation.<br>
The initial commercialization of DFMCs has been<br>
tried by some companies like UltraCell (United States)<br>
and Smart Fuel Cells (Germany) with the system<br>
ranging f Ether, promoter, electrocatalysis<br>
The initial commercialization of DFMCs has been<br>
tried by some companies like UltraCell (United States)<br>
and Smart Fuel Cells (Germany) with the system<br>
ranging from 25 to 1000 W; meanwh The initial commercialization of DFMCs has been<br>tried by some companies like UltraCell (United States)<br>and Smart Fuel Cells (Germany) with the system<br>ranging from 25 to 1000 W; meanwhile, a series of<br>DMFCs systems with a The initial commercialization of DFMCs has been<br>tried by some companies like UltraCell (United States)<br>and Smart Fuel Cells (Germany) with the system<br>ranging from 25 to 1000 W; meanwhile, a series of<br>DMFCs systems with a

**Example 12**<br> **Example 12 EVALUAT Example, the particles are detected** to enhanoneus the incorporation surface that support as analogies and the specific sur-<br>
sults in the particles agglomeration, migration and oxidation. For example, either Ni<sub></sub>  $\pm 0.48\%$  (*L. Electrochem.*) 2022, 28(1), 2106211 (2 of 12)<br>sults in the particles agglomeration, migration and oxidation. For example, either Ni-P or Fe-P coupled<br>leaching during the methanol oxidation reaction with P  $\pm \frac{1}{2}$  the support and the support of the support and the support and the support (MOR) process, leading to the rapid eatalytic performa ticles; besides, catalyst promoter modified carbon  $\pm$  42  $\pm$  22  $\pm$  22  $\pm$  22  $\pm$  22  $\pm$  23  $\pm$  23  $\pm$  23  $\pm$  24  $\pm$  24 $\pm$  24 $\pm$  24 $\pm$  24 $\pm$  24 $\pm$  24 $\pm$  24 $\pm$  24 $\pm$  24 $\pm$  24 $\pm$  24 $\pm$  24 $\pm$  24 $\pm$  24 $\pm$  $\pm \frac{1}{2}$  **Example 18**<br> the particles agglomeration, 2022, 28(1), 2106211 (2 of 12)<br>
ts in the particles agglomeration, migration and oxidation. For example, either Ni<sub>r</sub>P or Fe<sub>r</sub>P coupled<br>
chemp during the methodol oxidation reaction with Pt w  $#3E\% (L\text{ *Electrochem*.) } 2022, 28(1), 2106211 (2 of 12)$ <br>sults in the particles agglomeration, migration and oxidation. For example, either Ni<sub>3</sub>P or Fe<sub>3</sub>P coupled<br>costing during the methanol oxidation reaction with Pt was sho  $48/27$  *LEtermohem*, 2022. 28(1), 2106211 (2 of 12)<br>sults in the particles agglomeration, migration and oxidation. For example, either Ni=P or Fe-P coupled<br>leaching during the methanol oxidation reaction with Pt was show <sup>13</sup>(*LT+Cl, Literionham,* 2022, 28(1), 2106111(2 of 12)<br>
sults in the particles agglomeration, migration and oxidation. For example, either Ni-P or Fe-P coupled<br>
leaching during the methanol oxidation reaction<br>
(MOR) pro sults in the particles agglomeration, migration and oxidation. For example, either Ni<sub>p</sub>P or Fe<sub>p</sub>P coupled<br>leaching during the methanol oxidation reaction with Pt was shown to largely improve etanly<br>(MOR) process, leadin

for methanol oxidation, while in light of the high cost<br>
or to understand the catalysis mechanism and the devel-<br>
and instability of Ru, attention has been given to the oppenent of novel can<br>
and method alternatives<sup>[0,14</sup> and instability of Ru, attention has been given to the opment of novel eatalyst systems. While to our knowl-<br>
atternatives<sup>inathing</sup> One of the effective approaches is in edge, the summary report about TMPs system has not alternatives<sup>10,18</sup>. One of the effective approaches is in-<br>
dege, the summary report about TMPs system has not<br>
trocharing the calatyty promoter that can assist the acc-<br>
between provided. Considering their approaches th troducing the catalyst promoter that can assist the ac-<br>
trive sites in promoting mehranol oxidation. The cata-<br>
tive sites in permoting mehranol oxidation and oxidation and the performance of MOR. The cata-<br>
tive study r tive sites in promoting methanol oxidation. The eata-<br>
fuel cells technology as well as the promoting effect<br>
lyigh promotion group and character like in the findamental catalyisis, we have tried to review<br>
lyigh stabilit lyst promoter must have some good characters like in the fundamental catalysis, we have tried to review<br>high stability, good conductivity as well as the elec-<br>the adventus in the performance in the promotion of TMP as a c high stability, good conductivity as well as the clee-<br>the advances in the application of TMP as a catalytic<br>modiates adidescorption<sup>10,38</sup>. Transition metal phosph-<br>primetiple of the promoter is firstly described in this tronic structure tuming ability in promoting the inter-<br>monotion of methanol oxidation. The promotion is<br>ides (TMPs) have received wide attention in the water-<br>review, including the electronic effect of the fuel devices i mediates ad/desorption<sup>[0,1,10</sup>]. Transition metal phosph-<br>
principle of the promoter is firstly described in this<br>
did (TMPs) have recoived wide attention in the water-<br>
review, including the electronic spectrome of thei ides (TMPs) have received wide attention in the ware-<br>
voiw, including the electronic effect and the ligand<br>
splitting reaction because of their unique electronic effect on the bifurcional catalysis mechanism; and<br>
splitt <p>\n splitting reaction because of their unique electronic effect on the bifunctional catalysis mechanism; and cataly is mechanical at a higher number of 1MPs classified into nickel and catalyst promoters in enhancing the phosphides, in the physical analysis, etc.\n</p>\n<p>\n and calculated as ideal catalyst rhometers in enhancing the phosphides, in terms of the hybrid catalyst fibria-<br/>\n public active sites for methanol oxidation<sup>[49,48]</sup>. Com-<br/>\n are discussed in terms of the hybrid catalyst fibria-<br/>\n public active sites for methanol oxidation<sup>[49,48]</sup>. Then, the individual<br/>\n distribution of methods<sup>[40,48]</sup>. This method is the probability of methods of methods<sup>[40,48]</sup>. This method is the complexity and the previous methods of the high-<br/>\n of the and catalytic properties<sup>[47,10</sup>]. They have also been con-<br>
sidered as ideal catalytic promotes in enhancing the phosphides, iron phosphides, colouly phosphides, ecc.<br>
sidered as ideal catalytic spotter in enhancing the sidered as ideal eatalyst promoters in enhancing the phosphides, ion phosphides, colalr phosphids, etc.<br>
nohe active sites for methanol oxidation<sup>178</sup> 11. Com-<br>
are discussed in terms of the bybrid eatalyst finite-<br>
pared noble active sites for methanol oxidation<sup>126</sup>.<sup>211</sup>. Com-<br>
are discussed in terms of the hybrid catalyst fabrica-<br>
pared with metal oxides<sup>27</sup>, antilacte<sup>83</sup>, suffices<sup>29</sup>, TMPs simulated backin-<br>
have an electron-rich m

 $\# \ell \# (J. Electron) 2022, 28(1), 2106211 (2 of 12)$ <br>sults in the particles agglomeration, migration and oxidation. For example, either Ni<sub>2</sub>P or Fe<sub>2</sub>P coupled<br>leaching during the methanol oxidation reaction with Pt was shown to lar  $#E\# (J. Electrochem.) 2022, 28(1), 2106211 (2 of 12)$ <br>sults in the particles agglomeration, migration and<br>leaching during the methanol oxidation reaction<br>(MOR) process, leading to the rapid catalytic perfor-<br>formance for methanol oxi  $\# \&L \# (L \&Electrochem.)$  2022, 28(1), 2106211 (2 of 12)<br>
sults in the particles agglomeration, migration and<br>
leaching during the methanol oxidation reaction<br>
(MOR) process, leading to the rapid catalytic performance for metha  $\frac{1}{2}$   $\frac{4k\omega}{2}(L\text{ }Electrochem.) 2022, 28(1), 2106211 (2 of 12)$ <br>sults in the particles agglomeration, migration and oxidation For example, either Ni<sub>2</sub>P or Fe<sub>3</sub>P coupled<br>leaching during the methanol oxidation reaction with Pt was shown  $28(1)$ , 2106211 (2 of 12)<br>
oxidation. For example, either Ni<sub>2</sub>P or Fe<sub>2</sub>P coupled<br>
with Pt was shown to largely improve catalytic per-<br>
formance for methanol oxidation, and the high<br>
catalytic performance was attributed 28(1), 2106211 (2 of 12)<br>oxidation. For example, either Ni<sub>2</sub>P or Fe<sub>2</sub>P coupled<br>with Pt was shown to largely improve catalytic per-<br>formance for methanol oxidation, and the high<br>catalytic performance was attributed to th 28(1), 2106211 (2 of 12)<br>oxidation. For example, either Ni<sub>2</sub>P or Fe<sub>2</sub>P coupled<br>with Pt was shown to largely improve catalytic per-<br>formance for methanol oxidation, and the high<br>catalytic performance was attributed to th 28(1), 2106211 (2 of 12)<br>oxidation. For example, either Ni<sub>2</sub>P or Fe<sub>2</sub>P coupled<br>with Pt was shown to largely improve catalytic per-<br>formance for methanol oxidation, and the high<br>catalytic performance was attributed to th 28(1), 2106211 (2 of 12)<br>
oxidation. For example, either Ni<sub>2</sub>P or Fe<sub>2</sub>P coupled<br>
with Pt was shown to largely improve catalytic per-<br>
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catalytic performance was attributed t 28(1), 2106211 (2 of 12)<br>oxidation. For example, either Ni<sub>2</sub>P or Fe<sub>2</sub>P coupled<br>with Pt was shown to largely improve catalytic per-<br>formance for methanol oxidation, and the high<br>catalytic performance was attributed to th 28(1), 2106211 (2 of 12)<br>oxidation. For example, either Ni<sub>2</sub>P or Fe<sub>2</sub>P coupled<br>with Pt was shown to largely improve catalytic per-<br>formance for methanol oxidation, and the high<br>catalytic performance was attributed to th 28(1), 2106211 (2 of 12)<br>oxidation. For example, either Ni<sub>2</sub>P or Fe<sub>2</sub>P coupled<br>with Pt was shown to largely improve catalytic per-<br>formance for methanol oxidation, and the high<br>catalytic performance was attributed to th 28(1), 2106211 (2 of 12)<br>
oxidation. For example, either Ni<sub>2</sub>P or Fe<sub>2</sub>P coupled<br>
with Pt was shown to largely improve catalytic per-<br>
formance for methanol oxidation, and the high<br>
catalytic performance was attributed t . 2106211 (2 of 12)<br>
tion. For example, either Ni<sub>2</sub>P or Fe<sub>2</sub>P coupled<br>
Pt was shown to largely improve catalytic per-<br>
nece for methanol oxidation, and the high<br>
yitic performance was attributed to the hy-<br>
ilic propert 28(1), 2106211 (2 of 12)<br>oxidation. For example, either Ni<sub>2</sub>P or Fe<sub>2</sub>P coupled<br>with Pt was shown to largely improve catalytic per-<br>formance for methanol oxidation, and the high<br>catalytic performance was attributed to th 28(1), 2106211 (2 of 12)<br>oxidation. For example, either Ni<sub>2</sub>P or Fe<sub>2</sub>P coupled<br>with Pt was shown to largely improve catalytic per-<br>formance for methanol oxidation, and the high<br>catalytic performance was attributed to th 28(1), 2106211 (2 of 12)<br>oxidation. For example, either Ni<sub>2</sub>P or Fe<sub>2</sub>P coupled<br>with Pt was shown to largely improve catalytic per-<br>formance for methanol oxidation, and the high<br>catalytic performance was attributed to th 28(1), 2106211 (2 of 12)<br>oxidation. For example, either Ni<sub>2</sub>P or Fe<sub>2</sub>P coupled<br>with Pt was shown to largely improve catalytic per-<br>formance for methanol oxidation, and the high<br>catalytic performance was attributed to th 电化学(*J. Electrochem.*) 2022, 28(1), 2106211 (2 of 12)<br>ration, migration and oxidation. For example, either Ni<sub>2</sub>P or Fe<sub>2</sub>P coupled<br>pl oxidation reaction with Pt was shown to largely improve catalytic per-<br>rapid catalytic

leaching during the methanol oxidation reaction<br>
With Pt was shown to largely improve catalytic per-<br>
(MOR) process, leading to the rapid catalytic performance dogation, and the high<br>
mance degradation. The commercializat (MOR) process, leading to the rapid catalytic perfor-<br>mannee for methanol oxidation, and the high<br>manne degradation. The commercialization of DM-catalytic performance was attributed to the hy-<br>FCs relies on the highly eff mance degradation. The commercialization of DM-catalytic performance was attributed to the hy-<br>
FCs relies on the highly efficient ratalytic for drophilic property of TMP induced electronic effect<br>
emethanol oxidation, In FCs relies on the highly efficient catalyst for<br>
encontrile property of TMP induced electronic effect<br>
nenshaved coidation. In orter to solve the above prob-<br>
nenshaved Fermatical Courses and the ligand effecte<sup>82,32</sup>;<sup>Th</sup> methanol oxidation. In order to solve the above prob-<br>
lemathe defigured  $^{27}$ ; The physically mixed carbon<br>
lemathe area have been developed to enhance the inter-<br>
were found to share developed to channel enter-<br>
frace lems, novel earbon supports with a high specific sur-<br>
black and Cu<sub>P</sub>P as a mixed support of Pt nanoparticles<br>
frace area have been developed to enhance the inter-<br>
were found to have high catalytic activity for the<br>
ste face area have been developed to enhance the inter-<br>netro-<br>netro-<br>netro-netro-netro-netro-netro-netro-netro-netro-netro-netro-netro-netro-netro-netro-netro-netro-netro-netro-netro-netro-netro-netro-netro-netro-netro-netro action between the support and active metal nanopar-<br>electrooxidations of methanol and ethanol<sup>281</sup>,<br>ticles; besides, catalyst syponotr modified carbon<br>support as anchoring sites have also been done to in-<br>for methanol oxi ricles; besides, caralyst promoter modified carbon<br>since the promotion effect of TMP is efficient<br>support as anchoring sites have also been done to in-<br>methanol oxidation, and some significant works<br>recase the interaction. support as anchoring sites have also been done to in-<br>
for methanol oxidation, and some significant works<br>
rease the interaction.<br>
The actalyst system are been done to develop this kind of catalyst<br>
for methanol oxidation erease the interaction.<br> **EVAC acadayst system** that the set catalyst system from the revive on these columes for methanol oxidation, while in light of the high cost to understand the catalysis mechanism and the helpelu<br> Pt-Ru catalyst is currently the best eatalyst system (cm, the review on these advances would be helpful<br>of renthanol oxidation, while in light of the high cost to understand encalysis mechanisms and the devel-<br>and instabi  $28(1)$ ,  $2106211$  ( $2$  of 12)<br>oxidation. For example, either Ni<sub>2</sub>P or Fe<sub>2</sub>P coupled<br>with Pt was shown to largely improve catalytic per-<br>formance for methanol oxidation, and the high<br>dealytic performance was attributed  $\alpha$ ,  $\alpha$ (1),  $\alpha$ 100211 (2 01 12)<br>oxidation. For example, either Ni<sub>3</sub>P or Fe<sub>2</sub>P coupled<br>with Pt was shown to largely improve catalytic per-<br>formance for methanol oxidation, and the high<br>catalytic performance was attri oxidation. For example, either Ni<sub>2</sub>P or Fe<sub>2</sub>P coupled<br>with Pt was shown to largely improve catalytic per-<br>formance for methanol oxidation, and the high<br>catalytic performance was attributed to the hy-<br>drophilic property with Pt was shown to largely improve catalytic per-<br>formance for methanol oxidation, and the high<br>catalytic performance was attributed to the hy-<br>drophilic property of TMP induced electronic effect<br>and the ligand effect<sup>[</sup> formance for methanol oxidation, and the high<br>catalytic performance was attributed to the hy-<br>drophilic property of TMP induced electronic effect<br>and the ligand effect<sup>[ $56,77$ ]</sup>; The physically mixed carbon<br>black and Cu<sub></sub> catalytic performance was attributed to the hy-<br>drophilic property of TMP induced electronic effect<br>and the ligand effect<sup>[26,27]</sup>; The physically mixed carbon<br>black and Cu<sub>3</sub>P as a mixed support of Pt nanoparticles<br>were drophilic property of TMP induced electronic effect<br>and the ligand effect<sup>[ $\alpha$ , $\overline{z}$ ]</sup>; The physically mixed carbon<br>black and Cu<sub>3</sub>P as a mixed support of Pt nanoparticles<br>were found to have high catalytic activity fo and the ligand effect<sup> $(x, 27)$ </sup>, The physically mixed carbon black and Cu<sub>3</sub>P as a mixed support of Pt nanoparticles were found to have high catalytic activity for the electrooxidations of methanol and ethanol<sup>[28]</sup>. Sinc black and Cu<sub>3</sub>P as a mixed support of Pt nanoparticles<br>were found to have high catalytic activity for the<br>electrooxidations of methanol and ethanol<sup>281</sup>.<br>Since the promotion effect of TMP is efficient<br>for methanol oxidati were found to have high catalytic activity for the<br>electrooxidations of methanol and ethanol<sup>paj</sup>.<br>Since the promotion effect of TMP is efficient<br>for methanol oxidation, and some significant works<br>have been done to develop electrooxidations of methanol and ethanol<sup>281</sup>.<br>
Since the promotion effect of TMP is efficient<br>
for methanol oxidation, and some significant works<br>
have been done to develop this kind of catalyst sys-<br>
tem, the review on Since the promotion effect of TMP is efficient<br>for methanol oxidation, and some significant works<br>have been done to develop this kind of catalyst sys-<br>tem, the review on these advances would be helpful<br>to understand the ca for methanol oxidation, and some significant works<br>have been done to develop this kind of catalyst sys-<br>tem, the review on these advances would be helpful<br>to understand the catalysis mechanism and the devel-<br>opment of nove have been done to develop this kind of catalyst sys-<br>tem, the review on these advances would be helpful<br>to understand the catalysis mechanism and the devel-<br>opment of novel catalyst systems. While to our knowl-<br>edge, the s tem, the review on these advances would be helpful<br>to understand the catalysis mechanism and the devel-<br>opment of novel catalyst systems. While to our knowl-<br>edge, the summary report about TMPs system has not<br>been provided to understand the catalysis mechanism and the devel-<br>opment of novel catalyst systems. While to our knowl-<br>edge, the summary report about TMPs system has not<br>been provided. Considering their application in the<br>fuel cells t opment of novel catalyst systems. While to our knowledge, the summary report about TMPs system has not been provided. Considering their application in the fuel cells technology as well as the promoting effect in the full c edge, the summary report about TMPs system has not<br>been provided. Considering their application in the<br>fuel cells technology as well as the promoting effect<br>in the fundamental catalysis, we have tried to review<br>the advance been provided. Considering their application in the<br>fuel cells technology as well as the promoting effect<br>in the fundamental catalysis, we have tried to review<br>the advances in the application of TMP as a catalytic<br>promoter fuel cells technology as well as the promoting effect<br>in the fundamental catalysis, we have tried to review<br>the advances in the application of TMP as a catalytic<br>promoter for methanol oxidation. The promotion<br>principle of advances in the application of TMP as a catalytic<br>moter for methanol oxidation. The promotion<br>ciple of the promoter is firstly described in this<br>iew, including the electronic effect and the ligand<br>et on the bifunctional ca promoter for methanol oxidation. The promotion<br>principle of the promoter is firstly described in this<br>review, including the electronic effect and the ligand<br>effect on the bifunctional catalysis mechanism; and<br>then, typica principle of the promoter is firstly described in this<br>review, including the electronic effect and the ligand<br>effect on the bifunctional catalysis mechanism; and<br>then, typical examples of TMPs classified into nickel<br>phosp review, including the electronic effect and the ligand<br>effect on the bifunctional catalysis mechanism; and<br>then, typical examples of TMPs classified into nickel<br>phosphides, iron phosphides, cobalt phosphides, etc.<br>are dis effect on the bifunctional catalysis mechanism; and<br>then, typical examples of TMPs classified into nickel<br>phosphides, iron phosphides, cobalt phosphides, etc.<br>are discussed in terms of the hybrid catalyst fabrica-<br>tion an then, typical examples of TMPs classified into nickel<br>phosphides, iron phosphides, cobalt phosphides, etc.<br>are discussed in terms of the hybrid catalyst fabrica-<br>tion and their catalysis application for methanol oxi-<br>dati phosphides, iron phosphides, cobalt phosphides, etc.<br>are discussed in terms of the hybrid catalyst fabrica-<br>tion and their catalysis application for methanol oxi-<br>dation. Finally, the problems and challenges for this<br>hybr

# Promoter

are discussed in terms of the hybrid catalyst fabrica-<br>tion and their catalysis application for methanol oxi-<br>dation. Finally, the problems and challenges for this<br>hybrid catalysts system are also presented, and hope-<br>ful

 $\# \# \# (L \: \text{Electrochem.})$  2022, 28(1), 2106211 (3 of 12)<br>diates of CO-like species will be adsorbed over the thus, can be modified by adjusting the electronic<br>active sites of the Pt surface, and the strong affinity structure t  $\# \ell \neq (L \ \text{Electrochem.}) 2022, 28(1), 2106211 (3 of 12)$ <br>diates of CO-like species will be adsorbed over the<br>active sites of the Pt surface, and the strong affinity<br>makes it not easy for further desorption. Thus, the oc-<br>expecies  $\frac{d}{dt}$   $\frac{d}{dt}$  adsorbed over the thus, can be modified by adjusting the elec  $\frac{dE}{dt}(J. Electrowe hem.) 2022, 28(1), 2106211 (3 of 12)$ <br>diates of CO-like species will be adsorbed over the thus, can be modified by adjusting the electronic<br>active sites of the Pt surface, and the strong affinity structure to chang **there** (*L Electrochem.*) 2022, 28(1), 2106211 (3 of 12)<br>
diates of CO-like species will be adsorbed over the thus, can be modified by adjusting the electronic<br>
active sites of the Pt surface, and the strong affinity s **EVALUATION**<br> **EVALUATION** . Bagotzky et al. found that the CO intermediates are very stable at low potentials (< 0.5 V) and can be con-**EVALUAT EXAMORET (Example 10.5 V and 0.7 V and 0.7 V and 0.7 Planets of CO<sub>2</sub> on the protocol in the section of the Pt surface, and the strong affinity structure to change the adsorption strength of the makes it not easy**  $\text{# } \ell \neq 0 \text{ if } \ell \neq 0 \text{ if$ tions (Eqns  $(5)-(6)$ <sup>[19]</sup>.

$$
CH_3OH + Pt \rightarrow Pt-CH_2OH_{ads} + H^+ + e
$$
 (1  
Pt-CH<sub>2</sub>OH<sub>ads</sub> + Pt  $\rightarrow$  Pt<sub>2</sub>-CHOH<sub>ads</sub> + H<sup>+</sup> + e (2  
Pt-CIOH<sub>1</sub> + Pt<sub>2</sub> + COH<sub>1</sub> + H<sup>+</sup> + e (2)

$$
1 \text{ } \mathcal{L} \text{ } \mathcal{
$$

$$
P1_3-COH_{ads} \rightarrow 2PL+PL-CO_{ads}+H+e
$$
 (4)

$$
P \cup CQ_1 + P \cup C\Pi_2 \cup C\Pi_3 \quad \text{or} \quad Q \cap CQ_2 + H^+ \quad \text{or} \quad Q
$$

$$
M + H_1O \rightarrow M_1OH + H^+ + e^-
$$
 (7)

$$
Pt\text{-}CO_{ads} + M\text{-}OH_{ads} \rightarrow Pt + M^+ \text{ } CO_2 + H^+ + e^-(8)
$$

there is almost no CO intermediate on the surface of Pt, which reduces the but there is co-<br>
CH( $\theta$ H( $\theta$ ) and  $\theta$ ) and  $\theta$  and of Pt when the potential is higher than 0.7 V because th( $k^{\text{th}}/L$  *Electrochem*,) 2022, 28(1), 2106211 (3 of 12)<br>diates of CO-like species will be adsorbed over the thus, can be modified by adjusting the electronic<br>active sites of the Pt surface, and the strong affinity **E** *C*Hike species will be adsorbed over the thus, can be modified by adjusting the electronic<br>
s of CO-like species will be adsorbed over the thus, can be modified by adjusting the electronic<br>
e sit not easy for furth (*J. Electrochem.*) 2022, 28(1), 2106211 (3 of 12)<br>
orbed over the thus, can be modified by adjusting the electronic<br>
strong affinity structure to change the adsoption strength of the<br>
1. Thus, the oc-<br>
species<sup>[33,34</sup>]. (a) cause of the easy filling of the antibonding orbits, and th  $fE^2F(J. *Electrochem*)$  2022, 28(1), 2106211 (3 of 12)<br>
or of CO-like species will be adsorbed over the thus, can be modified by adjusting the electronic<br>
e sites of the Pt surface, and the strong affinity structure to c ectrochem.) 2022, 28(1), 2106211 (3 of 12)<br>
dover the thus, can be modified by adjusting the electronic<br>
graffinity structure to change the adsorption strength of the<br>
us, the oc-<br>
species<sup>[73, 34]</sup>. Based on the electron 2) the oxidation potential of  $CO_{ak}$  is decreased<sup>[20, 26]</sup>. In s of CO-like species will be advorbed over the "thus, can be medidined by adjusting the electronic<br>e sites of the Pt surface, and the strong affinity of the sixten to change the adsorption strength of the<br>sixt not easy extraordinal points. Solution the distance of the species of the specie (3) the TMPs, the metal is regarded as a hydride-acceps of CO-like species will be adsorbed over the thus, can be modified by adjusting the electronic<br>
sit on the strong of the Pt surface, and the strong affinity structure to change the adsorption strength of the<br>
sit not ea orbed over the thus, can be modified by adjusting the electronic<br>strong affinity structure to change the adsorption strength of the<br>1. Thus, the oc-<br>species<sup>131, 34]</sup>. Based on the electronic effect, the intro-<br>cition fro (4) tor center and P is the proton-acceptor center resulte sites of the Pt surface, and the strong affinity<br>
site into teasy for further desorption. Thus, the oc-<br>
species<sup>185, 94</sup>, Based on the electronic effect, the<br>
detrive sites will prevent the reaction from fur-<br>
duced se and the strong affinity<br>structure to change the adsorption strength of th<br>sorption. Thus, the oc-<br>species<sup>[33,34]</sup>. Based on the electronic effect, the intro<br>the reaction from fur-<br>duced second component can modulate the (5) ing from electron cloud deviation of metal M induced is it not easy for further desorption. Thus, the oc-<br>species<sup>157, 13</sup>. Based on the electronic effect, the introduction<br>giong on, and the largely reduced scaliyeir perform-<br>duced sconod component can modulate the adsorp-<br> us, the oc-<br>species<sup>13, 34]</sup>. Based on the electronic effect, the intro-<br>from fur-<br>duced second component can modulate the adsorp-<br>vic perfor-<br>tion of  $CO_{ab}$  by Pt, which is dependent on the center<br>effect<sup>[12, 30]</sup>. posit (6) by the lower electronegativity of P atoms. TMP of active sites will prevent the reaction from fur-<br>
duced second component can modulate the ac<br>
en langely reduced catalytic erfort-<br>
tion of CO<sub>ns</sub> by Pt, which is dependent on the c<br>
en langely reduced catalytic erfo the reaction from fur-<br>
the reaction from fur-<br>
duced second component can modulate the adsorp<br>
duced catalytic perfor-<br>
ton of CO<sub>ss</sub>, by Pt, which is dependent on the cente<br>
cO intermediates are<br>
the promoter and d-band (7) demonstrates strong application ability for water going on, and the largely reduced catalytic perfor-<br>
tion of CO<sub>ad</sub> by Pt, which is dependent on the center<br>
trake is happens resulted from the poisoning effect<sup>[0.20</sup>].<br>
trake the CO intermediates are to premoter and d-b c perfor-<br>tion of CO<sub>as</sub> by Pt, which is dependent on the center<br>frect<sup>[13,30</sup>]. position of the d-band of Pt. The interaction between<br>intes are<br>the promoter and d-band of Pt changes the electronic<br>structure of Pt surface (b) splitting reaction because of the robust water activanoe happens resulted from the poisoning effect<sup>(12,30</sup>) position of the d-band of Pt. The interaction between<br>
gotzky et al. found that the CO intermediates are the promoter and d-band of Pt changes the electronic<br>
prisch Bagotzky et al. found that the CO intermediates are<br>
be promoter and d-band of Pt changes the electronic<br>
very stable at low potential ( $\leq$  0.5 V) and can<br>
be trimuously ovidized to CO<sub>2</sub> between 0.5 V and 0.7 V,<br>
d-han very stable at low potentials (< 0.5 V) and can be con-<br>tructure of Pt surface, making the center of the<br>functosity oxidized to CO<sub>p</sub> hetwors 0.5 V and 0.7 V, d-band of Pt lower relative to the fermi level, and de-<br>functi tinuously oxidized to CO, between 0.5 V and 0.7 V,<br>
d-band of Pt lower relative to the Fermi level, and de-<br>
but there is almost no CO intermediate on the surface creases the electron back-donation from the adsor-<br>
of Pt but there is almost no CO intermediate on the surface<br>
of Pt when the potential is higher than 0.7 V because<br>
of Pt, which reduces the binding energy of the<br>
the youi be removed according to the following reac-<br>
that cO i of Pt when the potential is higher than 0.7 V because<br>
will be removed according on the following reac-<br>
translate to Pt, which reduces the binding energy of the<br>
trison (Eqns (S)-(6))<sup>im</sup>,<br>
trison for methanol of columer they will be removed according to the following reac-<br>
than dCO intermediate<sup>[27]</sup>. Therefore, the adsorption<br>
streets is weakened be-<br>
CH<sub>2</sub>OH(a)<sup>H</sup>)<sup>m</sup>, P+ -> Pt<sub>-C</sub>CH<sub>3O</sub>H<sub>3a</sub> + H<sup>+</sup> + c<sup>2</sup> (2) cause of the easy fillin tions (Eqns  $(S)-(6)^{1/8}$ ,  $SU(4)$  strength of CO<sub>ab</sub> on the Pt surface is weakened be-<br>CH( $SOH + Pt \to Pt$ -CH( $SOH_{ab} + H' + c$  (1) eause of the casy filling of the anitomology orbits, and<br> $Pt$ -CH( $\Theta H_{ab} + Pt \to Pt$ )-CH( $\Theta H_{ab} + H' + c$  ( CH<sub>O</sub>OH + Pt → Pt-CH<sub>O</sub>OH<sub>no</sub> + H' + c (1) cause of the easy filling of the antibonding orbits, and<br>
Pt-CH<sub>O</sub>H<sub>no</sub> + Pt → Pt<sub>2</sub>-CHOH<sub>no</sub> + H' + c (2) the oxidation potential of Co<sub>os</sub> is decreased<sup>78</sup><sup>20</sup>, and<br>
Pt<sub>+</sub>C-OH<sub></sub> Pt-CH<sub>3</sub>OH<sub>4a</sub> + Pt → Pt<sub>3</sub>-CHOH<sub>4a</sub> + H<sup>+</sup> + e (2) the oxidation potential of CO<sub>4a</sub> is decreased<sup>(26</sup><sub>3</sub>x). In<br>Pt<sub>F</sub>-CHOH<sub>4a</sub> + Pt --Pt<sub>P-</sub>COH<sub>4a</sub> + H<sup>+</sup> + c (3) the TMP<sub>5</sub>s, the metal is regarded as a hydrid-eace-<br>Pt<sub>F</sub> Pt<sub>r</sub>-CHOH<sub>aa</sub> + Pt<sub>r</sub>-> Pt<sub>r</sub>-COH<sub>aa</sub> + H<sup>+</sup> + e (3) the TMPs, the metal is regarded as a hydride-accep-<br>Pt<sub>r</sub>-COH<sub>aa</sub> -+ 2Pt+Pt-CO<sub>os</sub> + H<sup>+</sup> + e<sup>c</sup> (4) to recentr and P is the proton-acceptor center result-<br>Pt-H<sub>15</sub>O-H Pty-COH<sub>as</sub>  $\rightarrow$  2Pt + Pt-CO<sub>6s</sub> + H<sup>+</sup> c<sup>2</sup> (4) tor center and P is the proton-acceptor center result-<br>
Pt + H<sub>2</sub>O - Pt-COH<sub>as</sub> + H<sup>1</sup> + e<sup>2</sup> (5) ing from electron cloud deviation of metal M induced<br>
Pt-CO<sub>6s</sub> + Pt-OH<sub>as</sub> Pt + H(O -- Pt-OH<sub>36</sub> + H<sup>+</sup>+ e (5) ing from electron cloud deviation of metal M induced<br>Pt-CO<sub>ad</sub> + N-OH<sub>36</sub> - 2Pt+CO<sub>2</sub> + H<sup>+</sup> + c (6) by the lower electronegativity of P atoms. TMP<br>Pt-CO<sub>ad</sub> + N-OH<sub>36</sub> - Pt +M<sup>1</sup> CO<sub>2</sub> Pt-CO<sub>ta</sub>.+ M-OH<sub>ta</sub>  $\rightarrow$  Pt+M: CO<sub>2</sub> + F!<sup>+</sup> + e (8) spliting reaction because of the robust water activa-<br>At present, there are two main fundamental princi-<br>incomediby; and formedion of the oxygen-containing<br>ples for ef At present, there are two main fundamental princi-<br>
ion ability; and formation of the oxygen-containing<br>
plus for efficient catalyst construction, namely, bi- species can thus be helpful to the intermediates of<br>
functiona ples for efficient catalyst construction, namely, bi-<br>species can thus be helpful to the intermediates of<br>threthorol catalytic mechanism and electronic effect.<br>
CD-like species oxidation has<br>do on the above mechanism of t functional eatalytic mechanism and electronic effect.<br>
CO-like species oxidation based on the above mecha-<br>
The bifunctional catalytic mechanism was proposed mism (Fag  $(7)(-8)$ ). Moreover, the metallic properties<br>
by Wata The bifunctional catalytic mechanism was proposed<br>
mism (Eqns (7)-(8)). Moreover, the metallic properties<br>
by Watanabe<sup>20,33</sup> to explain the catalytic performance<br>
of PH-Ru catalyst system for methanol oxidation;<br>
cent Pt by Watamabe<sup>n, 13</sup><sub>1</sub> to explain the catalytic performance<br>of TMPs can change the electronic structure of adja-<br>of Pt-Ru catalytis system for methanol oxidation, two active centers on<br>binding energy positions cell  $H$  fis of Pt-Ru catalysts system for methanol oxidation; cent Pt metals, which is generally observed that the during during the methanol oxidation, two eative centers on binding energy posisions of Pt4 shift to two binding the e  $(28(1), 2106211 \text{ (3 of 12)}$ <br>thus, can be modified by adjusting the electronic<br>structure to change the adsorption strength of the<br>species<sup>[33, 34]</sup>. Based on the electronic effect, the intro-<br>duced second component can modu  $(28(1), 2106211 \text{ (3 of 12)}$ <br>thus, can be modified by adjusting the electronic<br>structure to change the adsorption strength of the<br>species<sup>[33, 34]</sup>. Based on the electronic effect, the intro-<br>duced second component can modu  $\frac{1}{28(1)}$ , 2106211 (3 of 12)<br>thus, can be modified by adjusting the electronic<br>structure to change the adsorption strength of the<br>species<sup>[33, 34]</sup>. Based on the electronic effect, the intro-<br>duced second component can  $28(1)$ ,  $2106211$  (3 of 12)<br>thus, can be modified by adjusting the electronic<br>structure to change the adsorption strength of the<br>species<sup>[33, 34]</sup>. Based on the electronic effect, the intro-<br>duced second component can mo  $(28(1), 2106211 \text{ (3 of 12)}$ <br>thus, can be modified by adjusting the electronic<br>structure to change the adsorption strength of the<br>species<sup>[33, 34]</sup>. Based on the electronic effect, the intro-<br>duced second component can modu  $(28(1), 2106211 \text{ (3 of 12)})$ <br>thus, can be modified by adjusting the electronic<br>structure to change the adsorption strength of the<br>species<sup>[33,34</sup>]. Based on the electronic effect, the intro-<br>duced second component can modul  $(28(1), 2106211)$  (3 of 12)<br>thus, can be modified by adjusting the electronic<br>structure to change the adsorption strength of the<br>species<sup>[33,34]</sup>. Based on the electronic effect, the intro-<br>duced second component can modu  $(28(1), 2106211 \text{ (3 of 12)}$ <br>thus, can be modified by adjusting the electronic<br>structure to change the adsorption strength of the<br>species<sup>[33,34]</sup>. Based on the electronic effect, the intro-<br>duced second component can modul  $(28(1), 2106211 \text{ (3 of 12)}$ <br>thus, can be modified by adjusting the electronic<br>structure to change the adsorption strength of the<br>species<sup>[33,34]</sup>. Based on the electronic effect, the intro-<br>duced second component can modul 28(1), 2106211 (3 of 12)<br>thus, can be modified by adjusting the electronic<br>structure to change the adsorption strength of the<br>species<sup>[33,34]</sup>. Based on the electronic effect, the intro-<br>duced second component can modulat . 28(1), 2106211 (3 of 12)<br>thus, can be modified by adjusting the electronic<br>structure to change the adsorption strength of the<br>species<sup>[33,34]</sup>. Based on the electronic effect, the intro-<br>duced second component can modul 28(1), 2106211 (3 of 12)<br>thus, can be modified by adjusting the electronic<br>structure to change the adsorption strength of the<br>species<sup>[33, 34]</sup>. Based on the electronic effect, the intro-<br>duced second component can modula stellation of Co<sub>ads</sub> on the method of CO<sub>ads</sub> is decreased to except the TMPs, then the SPecies<sup>(33, 34</sup>). Based on the electronic effect, the introduced second component can modulate the adsorption of CO<sub>as</sub> by Pt, whic  $(28(1), 2106211 \text{ (3 of 12)}$ <br>thus, can be modified by adjusting the electronic<br>structure to change the adsorption strength of the<br>species<sup>[33,34]</sup>. Based on the electronic effect, the intro-<br>duced second component can modul  $28(1)$ ,  $2106211$  (3 of 12)<br>thus, can be modified by adjusting the electronic<br>structure to change the adsorption strength of the<br>species<sup>[33, 34]</sup>. Based on the electronic effect, the intro-<br>duced second component can mo **EXECTS EXECTS** COLLET (COLLET TRIST).<br>
thus, can be modified by adjusting the electronic structure to change the adsorption strength of the species<sup>[33, 34</sup>]. Based on the electronic effect, the introduced second compone thus, can be modified by adjusting the electronic<br>structure to change the adsorption strength of the<br>species<sup>[33, 34]</sup>. Based on the electronic effect, the intro-<br>duced second component can modulate the adsorp-<br>tion of CO structure to change the adsorption strength of the<br>species<sup>[33,34]</sup>. Based on the electronic effect, the intro-<br>duced second component can modulate the adsorp-<br>tion of CO<sub>as</sub> by Pt, which is dependent on the center<br>positi species<sup>[33, 34</sup>]. Based on the electronic effect, the introduced second component can modulate the adsorption of CO<sub>ssk</sub> by Pt, which is dependent on the center position of the d-band of Pt. The interaction between the p duced second component can modulate the adsorption of  $CO_{ak}$  by Pt, which is dependent on the center position of the d-band of Pt. The interaction between the promoter and d-band of Pt changes the electronic structure of tion of  $CO_{\text{abs}}$  by Pt, which is dependent on the center<br>position of the d-band of Pt. The interaction between<br>the promoter and d-band of Pt changes the electronic<br>structure of Pt surface, making the center of the<br>d-band position of the d-band of Pt. The interaction between<br>the promoter and d-band of Pt changes the electronic<br>structure of Pt surface, making the center of the<br>d-band of Pt lower relative to the Fermi level, and de-<br>creases the promoter and d-band of Pt changes the electronic<br>structure of Pt surface, making the center of the<br>d-band of Pt lower relative to the Fermi level, and de-<br>creases the electron back-donation from the adsor-<br>bate to Pt, structure of Pt surface, making the center of the<br>d-band of Pt lower relative to the Fermi level, and de-<br>creases the electron back-donation from the adsor-<br>bate to Pt, which reduces the binding energy of the<br>Pt and CO in d-band of Pt lower relative to the Fermi level, and de-<br>creases the electron back-donation from the adsor-<br>bate to Pt, which reduces the binding energy of the<br>Pt and CO intermediate<sup>[27]</sup>. Therefore, the adsorption<br>streng creases the electron back-donation from the adsor-<br>bate to Pt, which reduces the binding energy of the<br>Pt and CO intermediate<sup>[27]</sup>. Therefore, the adsorption<br>strength of CO<sub>ask</sub> on the Pt surface is weakened be-<br>cause of bate to Pt, which reduces the binding energy of the<br>Pt and CO intermediate<sup>[27]</sup>. Therefore, the adsorption<br>strength of CO<sub><sup>aak</sub> on the Pt surface is weakened be-<br>cause of the easy filling of the antibonding orbits, and<br>t</sub></sup> Pt and CO intermediate<sup>[27]</sup>. Therefore, the adsorption<br>strength of CO<sub>ask</sub> on the Pt surface is weakened be-<br>cause of the easy filling of the antibonding orbits, and<br>the oxidation potential of CO<sub>ask</sub> is decreased<sup>[20, 2</sup> strength of CO<sub>ads</sub> on the Pt surface is weakened be-<br>cause of the easy filling of the antibonding orbits, and<br>the oxidation potential of CO<sub>sa</sub> is decreased<sup>[20, 26]</sup>. In<br>the TMPs, the metal is regarded as a hydride-acce cause of the easy filling of the antibonding orbits, and<br>the oxidation potential of  $CO_{ads}$  is decreased<sup>[20, 26]</sup>. In<br>the TMPs, the metal is regarded as a hydride-accep-<br>tor center and P is the proton-acceptor center resu the oxidation potential of  $CO_{ab}$  is decreased<sup>[20, 26]</sup>. In<br>the TMPs, the metal is regarded as a hydride-accep-<br>tor center and P is the proton-acceptor center result-<br>ing from electron cloud deviation of metal M induced<br> the TMPs, the metal is regarded as a hydride-acceptor center and P is the proton-acceptor center resulting from electron cloud deviation of metal M induced by the lower electronegativity of P atoms. TMP demonstrates stron tor center and P is the proton-acceptor center result-<br>ing from electron cloud deviation of metal M induced<br>by the lower electronegativity of P atoms. TMP<br>demonstrates strong application ability for water<br>splitting reacti ing from electron cloud deviation of metal M induced<br>by the lower electronegativity of P atoms. TMP<br>demonstrates strong application ability for water<br>splitting reaction because of the robust water activa-<br>simility; and fo by the lower electronegativity of P atoms. TMP<br>demonstrates strong application ability for water<br>splitting reaction because of the robust water activa-<br>splitting reaction because of the robust water activa-<br>tion ability; a demonstrates strong application ability for water splitting reaction because of the robust water activa-<br>tion ability; and formation of the oxygen-containing<br>species can thus be helpful to the intermediates of<br>CO-like spec splitting reaction because of the robust water activa-<br>tion ability; and formation of the oxygen-containing<br>species can thus be helpful to the intermediates of<br>CO-like species oxidation based on the above mecha-<br>nism (Eqn tion ability; and formation of the oxygen-containing<br>species can thus be helpful to the intermediates of<br>CO-like species oxidation based on the above mecha-<br>nism (Eqns (7)-(8)). Moreover, the metallic properties<br>of TMPs c species can thus be helpful to the intermediates of<br>CO-like species oxidation based on the above mecha-<br>nism (Eqns (7)-(8)). Moreover, the metallic properties<br>of TMPs can change the electronic structure of adja-<br>cent Pt m CO-like species oxidation based on the above mechanism (Eqns (7)-(8)). Moreover, the metallic properties of TMPs can change the electronic structure of adjacent Pt metals, which is generally observed that the binding ener nism (Eqns (7)-(8)). Moreover, the metallic properties<br>of TMPs can change the electronic structure of adja-<br>cent Pt metals, which is generally observed that the<br>binding energy positions of Pt 4f shift to low binding<br>energ of TMPs can change the electronic structure of adja-<br>cent Pt metals, which is generally observed that the<br>binding energy positions of Pt 4f shift to low binding<br>energy positions resulting from partial electron trans-<br>fer cent Pt metals, which is generally observed that the binding energy positions of Pt 4f shift to low binding energy positions resulting from partial electron transfer from TMP to Pt<sup>[20,35]</sup>. The electron transfer is due to 电化学(*J. Electrochem.*) 2022, 28(1), 2106211 (3 of 12)<br>be adsorbed over the thus, can be modified by adjusting the electronic<br>md the strong affinity structure to change the adsorption strength of the<br>orption. Thus, the oc

 $\# \ell \# (J. Electron) 2022, 28(1), 2106211 (4 of 12)$ <br>sponding phosphide promoter is classified by the results showed that Pt-Ni<sub>2</sub>P/graphene catalyst exhibit-<br>metal center and some examples of their application ed much higher catalyt

moter in the TMPs family used for methanol oxida-<br>on the Pt catalyst. Spectral analysis showed that the<br>droin. It has a hoxegonal crystal structure with highly reckeel and horizon<br>displayied and chemical stability for wat ion. It has a hexagonal crystal structure with high Pt-Ni<sub>3</sub>P-graphene manoparticles exhibited a hybrid<br>physical and chemical stability for water splitting re-<br>crystal and chemical stability for water splitting re-<br>partic physical and chemical stability for water splitting re-<br>
erystal structure with slightly reduced lattice parame-<br>
eactival to is cocellent Pt-like properties and or-<br>
ters. XPS data revealed that the Pt 4 f peak of 20%<br>
r action due to its excellent Pt-like properties and cor-<br>
ters. XPS data revealed that the Pt 4f peak of 20%<br>
resistance<sup>201</sup>. The effects of Ni<sub>2</sub>P arounds and Pt-Ni<sub>2</sub>P graphene significantly shifled about 0.4 eV to<br>
the rosion resistance<sup>(wg</sup>). The effects of Ni<sub>t</sub>P amounts and Pt-Ni<sub>t</sub>P-graphene significantly shifted about 0.4 eV to<br>the interaction between Pt and Ni<sub>j</sub>P on PtC catalyst the low binding energy direction (Figure 1(G)), ind the interaction between Pt and Ni<sub>2</sub>P on Pi/C catalyst<br>
the low binding energy direction (Figure 1(G)), indicat-<br>
for methanol oxidation were reported<sup>121</sup>. The Ni<sub>2</sub>P img as trong electron interaction resulting from some for methanol oxidation were reported<sup>121</sup>. The Ni<sub>3</sub><sup>p</sup> ing a strong electron interaction resulting from some<br>anapoprisies anchored ore the carbon support were electrons transfer from Ni<sup>2</sup>P to Pt. In addition, the<br>employ nanoparticles anchored over the curbon support were<br>
electrons transfer from Ni<sub>P</sub> to Pt. In addition, the<br>
employed to support the Pt nanoparticles by an im-<br>
strong electron interction between Pt and Ni<sub>P</sub><br>
pregration m employed to support the Pt nanoparticle by an im-<br>strong electron interaction between Pt and Ni<sub>2</sub>P<br>pregnation method and a microwave-assisted ethy-<br>imagenatieles was influenced by the content of Ni<sub>3</sub>P<br>ten glycol reducti pregration method and a microwave-assisted ethy-<br>nanoparticles was influenced by the content of Ni-P<br>the chere glyon reduction method, and the fine distribu-<br>in the system. When the content of Ni-P axa 20%, the<br>tion of th lene glyool reduction method, and the fine distribu-<br>in the system. When the content of Ni-P was 20%, the<br>
trion of the Pt namoparticies with the average particle calulyst and the best sami-CO poisoning ability and<br>
size tion of the Pt nanoparticles with the average particle<br>
size of 2.5 mm was 69 than the ochies of 2.5 mm was 69.9 and the extreme in (Figure 1(11-1)). By performing the physical characterial<br>
mized PtNi<sub>2</sub>P/C-30% catalyst size of 2.5 nm was obtained (Figure 1(A)). The opit-<br>
mized Pre-Ni-Pr-Ni-Pr-Ni-Pr-Ni-Pr-Ni-Pr-Ni-Pr-Ni-Pr-Ni-Pr-Ni-Pr-Ni-Pr-Ni-Pr-Ni-Pr-Ni-Pr-Ni-Pr-Ni-Pr-Ni-Pr-Ni-Pr-Ni-Pr-Ni-Pr-Ni-Pr-Ni-Pr-Ni-Pr-Ni-Pr-Ni-Pr-Ni-Pr-Ni-Pr-N mized Pt-Ni<sub>3</sub>P/C-30% catalyst showed significantly<br>higher proformance than Pt/C, Ni-Pt/C and P-Pt/C carditions and the cletterochemical measurements, it<br>higher performance than Pt/C, Ni-Pt/C and P-Pt/C carrietions and th higher performance than Pt/C, Ni-Pt/C and P-Pt/C erizations and the electrochemical measurements, it expansives (Figure 1 (Bi)). The improved performance was suggested that to higher elations between Pt be attributed to t entalysts (Figure 1(B)). The improved performance was suggested that the high catalytic performance can was attributed to the strong initeration between  $Pt$  be attributed to the Pt and Ni2P hybridization encour-<br>and Ni2P was attributed to the strong interaction between Pt be attributed to the Pt and Ni<sub>2</sub>P hybridization encount-<br>high phene catalysity correl during the one-set phytothermal process that<br>from Ni<sub>2</sub>P resulting in the pratial

metal center and some examples of their application  $\exists k \neq (L \text{ Electrochem.}) 2022, 28(1), 2106211 \text{ (4 of 12)}$ <br>sponding phosphide promoter is classified by the results showed that Pt-Ni<sub>2</sub>P/graphene catalyst exhibit-<br>metal center and some examples of their application ed much higher  $\frac{16}{2}$  (*J. Electrochem.*) 2022, 28(1), 2106211 (4 of 12)<br>sponding phosphide promoter is classified by the results showed that Pt-Ni<sub>3</sub>P/graphene catalyst exhibit-<br>metal center and some examples of their application e  $\begin{array}{lll}\n & \text{#1E}\ncong \text{(L Electrochem.) 2022, 28(1), 2106211 (4 of 12)} \\
 & \text{sponding phosphate promoter is classified by the results showed that Pt-Ni<sub>B</sub>P/graphene catalyst exhibit-  
metal center and some examples of their applicationed much higher catalytic activity and stability for\nfor methanol oxidation are discussed. It is concluded, the TMPs can promote the Pt-based catalyst for\nthat the TMPs can promote the Pt-based catalyst for\natributed the high catalytic performance to the im-  
method oxidation, while the real catalytic mecha-  
ing is still not clear, and more effort is required to-  
thus, promoting the electrooxidation kinetics of CO<sub>ab</sub>-  
our group<sup>DB</sup> simplified the experimental$  $\frac{d}{dt}\left(\frac{d}{dt}\right)\left(\frac{d}{dt}\right) = \frac{d}{dt}\left(\frac{d}{dt}\right)\left(\frac{d}{dt}\right) = \frac{d}{dt}\left(\frac{d}{dt}\right)\left(\frac{d}{dt}\right) = \frac{d}{dt}\left(\frac{d}{dt}\right)\left(\frac{d}{dt}\right) = \frac{d}{dt}\left(\frac{d}{dt}\right)\left(\frac{d}{dt}\right) = \frac{d}{dt}\left(\frac{d}{dt}\right)\left(\frac{d}{dt}\right) = \frac{d}{dt}\left(\frac{d}{dt}\right)\left(\frac{d}{dt}\right) = \frac{d}{dt}\left(\frac{d}{dt}\right)\left(\frac{d}{dt$ **EVALUATION**<br>
We the properties in the precise interaction to the translation of the translation of the translation<br>
the precise interaction that Pt-Ni<sub>3</sub>P/graphene catalyst exhibitioned center and some examples of their  $\pm \frac{1}{2}$   $\pm \frac$  $\frac{d}{dt}\left\{\frac{d}{dt}\left(f, \frac{d}{dt}\right) - \frac{d}{dt}\right\} = \frac{d}{dt}\left\{\frac{d}{dt}\left(f, \frac{d}{dt}\right) - \frac{d}{dt}\right\}$ <br>
Supporting phosphide promoter is classified by the results showed that Pt-Ni<sub>2</sub>P/graph<br>
metal center and some examples of their applicati  $\frac{1}{2}$  is the first catalyst pro-<br>
(Nickel phosphide promoter is classified by the results showed that Pt-NisP/graphene catalyst exhibitial<br>
enticated center and some examples of their application<br>
or methanol oxidatio **EVALUATION THE THE SET INTERT CONDUCT THE SET AND THE THE SET AND ANONGOTRIZED AND THE SET AND THE S Has a hexagonal manufology Has a head of the manufology Has a hexagonal critical structure in the manufology and the methanol oxidation are discussed. It is concluded methanol oxidation than PtVC alone, and the autho**  $\text{#}(E\#Z, Llermchem) \cdot 2022.28(1), 2106211 (4 of 12) \label{thm:4}$ <br>
sponding phosphide promoter is classified by the results showed that Pt-Ni-P'<br>graphene catalyst exhibit-<br>
metal center and some examples of their application ed much the  $t^2/2$ . Hetomology, 2022, 28(1), 21021, 14 (4712)<br>
sponding phosphide promoter is classified by the results showed that Pt-Ni<sub>1</sub>P/graphene catalyst exhibi-<br>
metal center and some examples of their application of much **FIGPF(LE Electrochem.)** 2022, 28(1), 2106211 (4 of 12)<br>
sponding phosphide promoter is classified by the results showed that Pt-Ni<sub>3</sub>P graphene catalyst exhibit-<br>
metal center and some examples of their application ed m sponding phosphide promoter is classified by the results showed that Pt-Ni<sub>2</sub>P/graphene catalyst exhibit-<br>metal center and some examples of their application<br>of much higher catalytic activity and stability for<br>for methano sponding phosphide promoter is classified by the results showed that Pe-Ni<sub>2</sub>P/graphene eatalyst exhibiterarity ener for the methanol oxidation are ancher for their application ed much higher catalytic activity and stabil metal center and some examples of their application<br>or d much higher catalytic activity and stability for<br>the methodox constants and the sucessed. It is concluded method oxidation than PVC alone, and the authors<br>that the for methanol oxidation are discussed. It is concluded methanol oxidation than  $PVC$  alone, and the authors<br>methanol oxidation, while the Pelsost catativity or attributed the high catalytic proferance to the im-<br>methanol ox that the TMPs can promote the Pt-based catalyst for<br>method on kingin eatalytic performance to the im-<br>method oxidation, while the real catalytic mechanism proved electron transfer among Pt, high and graphene,<br>mism is stil methanol oxidation, while the real catalytic mechanism proved electron transfer among Pt, Ni<sub>j</sub>P and graphene,<br>
nis in still not clear, and more clibri is required to thus, promoting the clear<br>
ward the precise interactio nism is still not clear, and more effort is required to-<br>thus, promoting the electrooxidation kinetics of CO<sub>4</sub>,<br>standing in their catalytic mechanism. Come group<sup>s i</sup>s implified the experimental process and<br>standing in t ward the precise interaction tunning and the under-<br> **Simplified** the experimental process and<br> **SiX (Figure 10.5 nm** was obtained the successfully prepared ultraine PN-NB-graphene<br> **3. Nickel Phosphide**<br>
Nickel phosphide standing in their catalytic mechanism.<br> **SINCEN Phosphide**<br> **SINCEN Phosphide**<br> **Nickel phosphide (NiP)** is the first catalyst process are ampleasingly as simple one-starp is obset and Nickel phosphide (NiP) is the first **3 Nickel Phosphide**<br>
Nickel phosphide<br>
Nickel phosphapide (Ni<sub>c</sub>P) is the first catalyst pro-<br>
method, and further studied the o-catalysis of Ni<sub>2</sub>P<br>
method, and further studied the o-catalysis of Ni-Pt-Ni-Pt-Ri-Pt-Ni-Pt Nickel phosphide (Ni<sub>r</sub>P) is the first catalyst pro-<br>method, and firther studied the co-catalysis of Ni<sub>r</sub>P<br>notes in the TMPs family used for methanol oxida-<br>note in the TMB standard crystal structure with high<br> $P_1N_1P_2$ 28(1), 2106211 (4 of 12)<br>results showed that Pt-Ni<sub>2</sub>P/graphene catalyst exhibit-<br>ed much higher catalytic activity and stability for<br>methanol oxidation than Pt/C alone, and the authors<br>attributed the high catalytic perfo 28(1), 2106211 (4 of 12)<br>results showed that Pt-Ni<sub>2</sub>P/graphene catalyst exhibit-<br>ed much higher catalytic activity and stability for<br>methanol oxidation than Pt/C alone, and the authors<br>attributed the high catalytic perfo 28(1), 2106211 (4 of 12)<br>results showed that Pt-Ni<sub>2</sub>P/graphene catalyst exhibit-<br>ed much higher catalytic activity and stability for<br>methanol oxidation than Pt/C alone, and the authors<br>attributed the high catalytic perfo 28(1), 2106211 (4 of 12)<br>results showed that Pt-Ni<sub>2</sub>P/graphene catalyst exhibit-<br>ed much higher catalytic activity and stability for<br>methanol oxidation than Pt/C alone, and the authors<br>attributed the high catalytic perfo 28(1), 2106211 (4 of 12)<br>results showed that Pt-Ni<sub>2</sub>P/graphene catalyst exhibit-<br>ed much higher catalytic activity and stability for<br>methanol oxidation than Pt/C alone, and the authors<br>attributed the high catalytic perfo 28(1), 2106211 (4 of 12)<br>results showed that Pt-Ni<sub>2</sub>P/graphene catalyst exhibit-<br>ed much higher catalytic activity and stability for<br>methanol oxidation than Pt/C alone, and the authors<br>attributed the high catalytic perfo 28(1), 2106211 (4 of 12)<br>results showed that Pt-Ni<sub>2</sub>P/graphene catalyst exhibit-<br>ed much higher catalytic activity and stability for<br>methanol oxidation than Pt/C alone, and the authors<br>attributed the high catalytic perfo 28(1), 2106211 (4 of 12)<br>results showed that Pt-Ni<sub>2</sub>P/graphene catalyst exhibit-<br>results showed that Pt-Ni<sub>2</sub>P/graphene catalyst exhibit-<br>ed much higher catalytic activity and stability for<br>methanol oxidation than Pt/C a . 28(1), 2106211 (4 of 12)<br>results showed that Pt-Ni<sub>2</sub>P/graphene catalyst exhibit-<br>ed much higher catalytic activity and stability for<br>methanol oxidation than Pt/C alone, and the authors<br>attributed the high catalytic per . 28(1), 2106211 (4 of 12)<br>results showed that Pt-Ni<sub>2</sub>P/graphene catalyst exhibit-<br>ed much higher catalytic activity and stability for<br>methanol oxidation than Pt/C alone, and the authors<br>attributed the high catalytic per 28(1), 2106211 (4 of 12)<br>results showed that Pt-Ni<sub>2</sub>P/graphene catalyst exhibit-<br>results showed that Pt-Ni<sub>2</sub>P/graphene catalyst exhibit-<br>ed much higher catalytic activity and stability for<br>methanol oxidation than Pt/C a 28(1), 2106211 (4 of 12)<br>results showed that Pt-Ni<sub>2</sub>P/graphene catalyst exhibit-<br>results showed that Pt-Ni<sub>2</sub>P/graphene catalyst exhibit-<br>ed much higher catalytic activity and stability for<br>methanol oxidation than Pt/C a 28(1), 2106211 (4 of 12)<br>results showed that Pt-Ni<sub>2</sub>P/graphene catalyst exhibit-<br>results showed that Pt-Ni<sub>2</sub>P/graphene catalyst exhibit-<br>ed much higher catalytic activity and stability for<br>methanol oxidation than Pt/C a .28(1), 2106211 (4 of 12)<br>results showed that Pt-Ni<sub>2</sub>P/graphene catalyst exhibit-<br>results showed that Pt-Ni<sub>2</sub>P/graphene catalyst exhibit-<br>ed much higher catalytic activity and stability for<br>methanol oxidation than Pt/C results showed that Pt-Ni<sub>2</sub>P/graphene catalyst exhibit-<br>results showed that Pt-Ni<sub>2</sub>P/graphene catalyst exhibit-<br>ed much higher catalytic activity and stability for<br>methanol oxidation than Pt/C alone, and the authors<br>att results showed that Pt-Ni<sub>2</sub>P/graphene catalyst exhibit-<br>ed much higher catalytic activity and stability for<br>methanol oxidation than Pt/C alone, and the authors<br>attributed the high catalytic performance to the im-<br>proved ed much higher catalytic activity and stability for<br>methanol oxidation than Pt/C alone, and the authors<br>attributed the high catalytic performance to the im-<br>proved electron transfer among Pt, Ni<sub>2</sub>P and graphene,<br>thus, pr methanol oxidation than Pt/C alone, and the authors<br>attributed the high catalytic performance to the im-<br>proved electron transfer among Pt, Ni<sub>2</sub>P and graphene,<br>thus, promoting the electrooxidation kinetics of CO<sub>ak</sub>-<br>Our attributed the high catalytic performance to the im-<br>proved electron transfer among Pt, Ni<sub>2</sub>P and graphene,<br>thus, promoting the electrooxidation kinetics of  $CO_{abs}$ <br>Our group<sup>[26]</sup> simplified the experimental process and<br> proved electron transfer among Pt, Ni<sub>2</sub>P and graphene,<br>thus, promoting the electrooxidation kinetics of  $CO_{abs}$ <br>Our group<sup>[26]</sup> simplified the experimental process and<br>successfully prepared ultrafine Pt-Ni<sub>2</sub>P-graphene<br>na thus, promoting the electrooxidation kinetics of  $CO<sub>abs</sub>$ <br>Our group<sup>[36]</sup> simplified the experimental process and<br>successfully prepared ultrafine Pt-Ni<sub>2</sub>P-graphene<br>nanoparticles by a simple one-step hydrothermal<br>method Our group<sup>[26]</sup> simplified the experimental process and<br>successfully prepared ultrafine Pt-Ni<sub>2</sub>P-graphene<br>nanoparticles by a simple one-step hydrothermal<br>method, and further studied the co-catalysis of Ni<sub>2</sub>P<br>on the Pt c successfully prepared ultrafine Pt-Ni<sub>3</sub>P-graphene<br>nanoparticles by a simple one-step hydrothermal<br>method, and further studied the co-catalysis of Ni<sub>3</sub>P<br>on the Pt catalyst. Spectral analysis showed that the<br>Pt-Ni<sub>3</sub>P-gra nanoparticles by a simple one-step hydrothermal<br>method, and further studied the co-catalysis of Ni<sub>2</sub>P<br>on the Pt catalyst. Spectral analysis showed that the<br>Pt-Ni<sub>2</sub>P-graphene nanoparticles exhibited a hybrid<br>crystal stru method, and further studied the co-catalysis of Ni<sub>3</sub>P<br>on the Pt catalyst. Spectral analysis showed that the<br>Pt-Ni<sub>3</sub>P-graphene nanoparticles exhibited a hybrid<br>crystal structure with slightly reduced lattice parame-<br>ters on the Pt catalyst. Spectral analysis showed that the<br>Pt-Ni<sub>2</sub>P-graphene nanoparticles exhibited a hybrid<br>crystal structure with slightly reduced lattice parame-<br>ters. XPS data revealed that the Pt 4f peak of 20%<br>Pt-Ni<sub>2</sub> Pt-Ni<sub>3</sub>P-graphene nanoparticles exhibited a hybrid<br>erystal structure with slightly reduced lattice parame-<br>ters. XPS data revealed that the Pt 4f peak of 20%<br>Pt-Ni<sub>3</sub>P-graphene significantly shifted about 0.4 eV to<br>the l erystal structure with slightly reduced lattice parame-<br>ters. XPS data revealed that the Pt 4f peak of 20%<br>Pt-Ni<sub>2</sub>P-graphene significantly shifted about 0.4 eV to<br>the low binding energy direction (Figure 1(G)), indicat-<br> teraction. Pt-Ni<sub>2</sub>P-graphene significantly shifted about 0.4 eV to<br>the low binding energy direction (Figure 1(G)), indicat-<br>ing a strong electron interaction resulting from some<br>electrons transfer from Ni<sub>2</sub>P to Pt. In addition, th Example 1.1 and the meaning of irrection (Figure 1(G)), indicated a strong electron interaction resulting from some electrons transfer from Ni<sub>2</sub>P to Pt. In addition, the ong electron interaction between Pt and Ni<sub>2</sub>P the a strong electron interaction resulting from some<br>trons transfer from Ni<sub>2</sub>P to Pt. In addition, the<br>g electron interaction between Pt and Ni<sub>2</sub>P<br>particles was influenced by the content of Ni<sub>2</sub>P<br>e system. When the conten is electron interaction resulting from some<br>
ansfer from Ni<sub>2</sub>P to Pt. In addition, the<br>
tron interaction between Pt and Ni<sub>2</sub>P<br>
es was influenced by the content of Ni<sub>2</sub>P<br>
m. When the content of Ni<sub>2</sub>P was 20%, the<br>
1 th electrons transfer from Ni<sub>2</sub>P to Pt. In addition, the<br>strong electron interaction between Pt and Ni<sub>2</sub>P<br>nanoparticles was influenced by the content of Ni<sub>2</sub>P<br>in the system. When the content of Ni<sub>2</sub>P was 20%, the<br>catalys strong electron interaction between Pt and Ni<sub>3</sub>P<br>nanoparticles was influenced by the content of Ni<sub>3</sub>P<br>in the system. When the content of Ni<sub>3</sub>P was 20%, the<br>catalyst had the best anti-CO poisoning ability and<br>the electr nanoparticles was influenced by the content of Ni<sub>2</sub>P<br>in the system. When the content of Ni<sub>2</sub>P was 20%, the<br>catalyst had the best anti-CO poisoning ability and<br>the electrooxidation performance of alcohol fuel<br>(Figure 1(H in the system. When the content of Ni<sub>3</sub>P was 20%, the<br>catalyst had the best anti-CO poisoning ability and<br>the electrooxidation performance of alcohol fuel<br>(Figure 1(H-I)). By performing the physical charact-<br>erizations a 电化学(*J. Electrochem.*) 2022, 28(1), 2106211 (4 of 12)<br>
is classified by the results showed that Pt-Ni<sub>2</sub>P/graphene catalyst exhibit-<br>
es of their application ed much higher catalytic activity and stability for<br>
ussed. It

 $Fe<sup>δ+</sup>$  and  $P<sup>δ</sup>$  is facile to the mass and charge transfers, catalyst had the best anti-CO poisoning ability and<br>the electrooxidation performance of alcohol fuel<br>(Figure 1(H-I)). By performing the physical charact-<br>erizations and the electrochemical measurements, it<br>was suggested t the electrooxidation performance of alcohol fuel<br>(Figure 1(H-I)). By performing the physical charact-<br>erizations and the electrochemical measurements, it<br>was suggested that the high catalytic performance can<br>be attributed (Figure 1(H-I)). By performing the physical characterizations and the electrochemical measurements, it was suggested that the high catalytic performance can be attributed to the Pt and Ni<sub>2</sub>P hybridization encountered dur erizations and the electrochemical measurements, it<br>was suggested that the high catalytic performance can<br>be attributed to the Pt and Ni<sub>2</sub>P hybridization encoun-<br>tered during the one-step hydrothermal process that<br>enhanc was suggested that the high catalytic performance can<br>be attributed to the Pt and Ni<sub>2</sub>P hybridization encoun-<br>tered during the one-step hydrothermal process that<br>enhanced the anti-poisoning ability and electronic in-<br>ter be attributed to the Pt and Ni<sub>2</sub>P hybridization encoun-<br>tered during the one-step hydrothermal process that<br>enhanced the anti-poisoning ability and electronic in-<br>teraction.<br>**4 Iron Phosphide**<br>Iron phosphide (FeP) with s



-1 **Example 1991**<br> **Example 10**<br> **Example 200**<br> **Example 20** 

**Example 11**<br> **Example 1** All  $\frac{1}{2}$ <br> **Example 1** All  $\frac{1}{2}$ <br> **Example 11** All  $\frac{1}{2}$ <br> **Example 11 Example and the station reaction reactio Bioding energy**  $i(\mathbf{v})$ <br> **Figure 1** (A) High-resolution transmission electrom nicroscopic image of a PeNi<sub>2</sub>PC-39% sample, (H) cycles when<br>
(C) power-density curves for fiel cells employing Pi-Ni<sub>2</sub>PC-30%, Pi-Ni<sub>2</sub>PC, **Figure 1** (A) High-resolution transmission electron microscopic image of a Pt-Ni-PC-30% sample, (B) cyclic voltammograms and<br>(C) power-density curves for fuel cells employing F-Ni-JPC-30% (Pr-NC-, Pt-NC-JM and FC-HR as a (C) power-density curves for fact cells employing Pt-Ni-PC-30%, Pt-Ni-C, Pt-PC, PtC-JM and PtC-H as unode catalysts<sup>[6]</sup>.<br>
Steady-state polarization curves (O) and power-density curves of the elects employing (i.) PHk-Ni-Sieady-state polarization curves (D) and power-density curves for fitel cells employing (E) PRE-Ni-P'(C-40%, (I) commercial PREW<br>C-JM as anode catalytis<sup>29</sup><sup>2</sup>, (O) High-resolution XPS spectra of Pe4f, (H) CV curves of th CJM as anode eathly same. (ii) High-resolution XPS spectra of Pt-4f, (H) CV curves of the prepared catalysts measured in 0.5 mol-1.<sup>1</sup><br>
H<sub>3</sub>G), containing 1 mol-1.<sup>2</sup> CH5OH at a scan rate of 50 mV-s<sup>-2</sup> and (0) specific a H<sub>3</sub>O<sub>6</sub> containing 1 not-1.<sup>1</sup> CH<sub>3</sub>OH at a sean rate of 50 mV ·s<sup>2</sup> and (1) specific activity and mass activity at the peak potential for methunol existingine". (color on line)<br>The better resistance to CO poisoning was We find that the catalytic strivity and the stricting ore-shell structured catalyst specified or  $\mathbb{R}^n$ . The catalytic performance of  $\mathbb{R}^n$  with  $P$  and  $P$ **Propagation**<br> **Propagation**<br> **PHOSE SECUTE ANCALLY CONSULTER CONSULTER SECUTE AND PROPAGATION SECUTE AND PROPAGATION SECUTE AND PROPAGATION SECURE USE CALCUTE AND PROPAGATION (I) precific activity and mass activity at th EXERCTS**<br> **EXERCTS**<br> **EXECTS**<br> **EXECTS**<br> **EXECTS**<br> **EXECTS**<br> **EXECTS**<br> **EXECTS**<br> **EXECTS**<br> **EXECTS**<br> **EXECTS**<br> **Example 12**<br> **Example 12**<br> **Example 12**<br> **Example 12**<br> **Example Core-shell structured catalysts** (B) cyclic voltammograms and<br> **Example of Pt-Ni-P/C.** Pt/C-JM and Pt/C-H as anode catalysts <sup>[25]</sup>.<br>
Ideals employing (E) P when  $\frac{1}{2}$  and  $\frac{10\%}{10\%}$  and  $\frac{20\%}{10\%}$  and  $\frac{10\%}{10\%}$  and  $\frac{10\%}{10\%}$  and  $\frac{10\%}{10\%}$  are ptrofing of PtNig-G PtNig-G PtO-H<br>ige of a Pt-NigP/C-30% sample, (B) cyclic voltammograms and<br>pt PtNi/ vs.SCE)<br>  $P^{1.56P_{2}}$  correspondence for the catalytic performance of a Pt-Ni<sub>2</sub>PC-3 Pt-Ni<sub>2</sub>PC-3 performance for methanol catalytic Pt-Ni<sub>2</sub>C Pt-Ni<sub>2</sub>PC-40%, (F) commercial PtRu/<br>
(H) CV curves of the prepared catalysts age of a Pt-Ni<sub>2</sub>P/C-30% sample, (B) cyclic voltammograms and<br>
pt-Ni/C, Pt-P/C, Pt/C-JM and Pt/C-H as anode catalysts<sup>188</sup>.<br>
el cells employing (E) PtRu-Ni<sub>2</sub>P/C-40%, (F) commercial PtRu/<br>
(H) CV curves of the prepared ea , Pt-Ni/C, Pt-P/C, Pt/C-JM and Pt/C-H as anode catalysts<sup>[25]</sup>.<br>
El cells employing (E) PtRu-Ni<sub>2</sub>P/C-40%, (F) commercial PtRu/<br>
(H) CV curves of the prepared eatalysts measured in 0.5 mol·L<sup>1</sup><br>
(1) specific activity and el cells employing (E) PtRu-Ni<sub>2</sub>P/C-40%, (F) commercial PtRu/<br>
(H) CV curves of the prepared eatalysts measured in 0.5 mol·L<sup>4</sup><br>
(I) specific activity and mass activity at the peak potential for<br>
catalyst system have hig (H) CV curves of the prepared catalysts measured in 0.5 mol·L<sup>-1</sup><br>(I) specific activity and mass activity at the peak potential for<br>catalyst system have high catalytic activity and the<br>anti-poisoning ability for methanol (I) specific activity and mass activity at the peak potential for<br>catalyst system have high catalytic activity and the<br>anti-poisoning ability for methanol electro-oxidation<br>compared with a controlled  $Pt/C$  catalyst (Figure



different PtRu catalysts in 0.5 mol·L<sup>-1</sup> H<sub>2</sub>SO<sub>4</sub>/1 mol·L<sup>-1</sup> CH<sub>3</sub>OH solution at 0.6 V for 3600 s; (F) CO<sub><sup>ak</sub></sup> stripping voltammograms</sub> of PtRu@FeP 1:1, PtRu/C-H and PtRu/C-JM catalysts in 0.5 mol $\cdot$ L<sup>-1</sup> H<sub>2</sub>SO<sub>4</sub> solution<sup>[20]</sup>. (color on line)

**EVALUATION CONSULTERT CONSULTERT CONSULTERT CONSULTERT (FOLD VICENCIS CONSULTERT ARE CONSULTERT (FOLD VICENCIS CONSULTERT (FOLD VICENCIS CONSULTERT (FOLD VICENCIS CONSULTERT). This core-stollation of the particle of the PERICE CONSERVANTS AND EXECUTE CONSERVANTS AND EXECUTE CONSERVANTS (CONSERVANTS) CONSERVANTS (CONSERVANTS) AND THE CONSERVANTS (CONSERVANTS) (D) The electrocatalysis potential and the catalysts for methanol occurrence of** E<br>
E  $\frac{1}{4s^2}$ <br>  $\frac{1}{4s^2}$ <br>  $\frac{1}{4s^2}$ <br>  $\frac{1}{s^2}$ <br>  $\frac{1}{s^2}$ <br>  $\frac{1}{s^2}$ <br>  $\frac{1}{s^2}$ <br>  $\frac{1}{s^2}$ <br> **Figure 2** (A-B) TEM images of P-Fe-P sample, (C) cyclic volummorganus of P-Fe-P and PtC catalysts for methan **Example 1.1** The complete of the benchmark commentation of the benchmark commentation of the set of the benchmark commentation  $\frac{1}{2}$  of the benchmark commentation  $\frac{1}{2}$  of the cat-<br> **Figure 2** (A-H) IT-M images o **Figure 2** (A-B) TEM images of Pt-Fe<sub>P</sub> sample, (C) cyclic voltammograms of Pt-FeP and PrC catalysts for methanol oxidation<sup>171</sup>,<br>(D)The electrocentalytic performance of different PiRu catalysts for methanol electro-oxida **Figure 2** (A-H) TEM images of PE-ley maple, (C) gotic volument<br>params of PE-ley and PEC catalysis for methanol existence in the catalysis for methanol existence of different PRu catalysis in 0.5 mol - L<sup>1</sup> ERO/1 mol - L<sup></sup> (1)) The electrocealytic performance of different FePu catalytis for methanol electron-existance; (1): Chonomappeometric curves of of Hirdual directi PRG calalysis in 0.5 msi - L' 14,50*x* msi - L' CH(OH solution at 0.6 V for 500 s; (1) CO<sub>sa</sub> stripping volummorgnums<br>
of PRG(C catalyst and PRG(C-JM eatilysts in 0.5 mol -1.<sup>4</sup> HSO, solution<sup>28</sup>; (color on line)<br> or risingurer 1.1, riskies An and riskies Society can be a riskie of the manifold of the adsorption of intermediates, thus, it has received by (Figure 2(D)). The largely improved cata and desorption of intermediates, thus lyst stability compared to the PRWC reference cata-<br>
large attention for water splitting reaction<br>
systs was observed by chronoamperometric test for<br>
characters make it be a suitable platform<br>
3600 s (Figure 2(E)). The CO lysts was observed by chronoamperometric test for<br>
characters make it be a suitable pl<br>
3600 s (Figure 2(E)). The CO stripping voltammograms<br>
the Pt based catalysts for methan<br>
showed that the prepared PRu@FeP catalyst ha

PtRuC catalyst and home-made PtRuC catalyst, re-<br>
modest binding energy is beneficial to the adsorption<br>
specetively (frigure 2(D)). The largely improved cata-<br>
and desorption of intermediates, thus, it has received<br>
lyst PRWC catalyst and home-made PRWC catalyst, re-<br>spectrively (Figure 2(D)). The Largely improved cata-<br>slag and descoption of intermediates, thus, it has received pyer state-<br>if yets stability exampled to the PRWC reference spectively (Figure 2(D)). The largely improved eata-<br>
and desorption of intermediates, thus, it has received<br>
lyst stability compared to the PRIuC reference can-<br>
lyst savis observed by chronomperometric test for<br>
charact 00 s (Figure 2(E)). The CO stripping voltammograms the Pt based catalysts for methanol oxidation, and it he mean a variable the heyeard PRRu@Fe teatly at has a variable for the as a variable for the sample in the predicti showed that the prepared PRRu@FeP catalyst had ex-<br>
cellent tolerance to CO poisoning effect with the For example, CoP supported on graphitized carbon<br>
epeak potential and the onset potential of CO oxida-<br>
fair-incated by **Example 18**<br>
The Based catalysts for methanol oxidation<sup>[27]</sup>, and  $\overline{R}$   $\overline{R}$  has a variety of stoichiometry such as CoP and Co2P. For  $\frac{F_0^{0.00}}{2000 \times 2000 \times 3000}$ <br>  $\frac{F_0^{0.00}}{40.15}$ Fabrication<br>  $\overline{f}_{(8)}^{2,100}$ <br>  $\overline{f}_{(8)}^{2,100}$ <br>  $\overline{f}_{(8)}^{2,100}$ <br>
oggrams of Pt-Fe<sub>2</sub>P and Pt/C catalysts for methanol oxidation<sup>127</sup>.<br>
Internation electro-oxidation; (E) Chronoamperometric curves of<br>
ution at 0.6 **Example 1** and Pt/C catalysts for methanol oxidation<sup>127</sup>.<br> *Ans*  $\frac{1}{250}$  and Pt/C catalysts for methanol oxidation<sup>127</sup>.<br>
northanol electro-oxidation; (E) Chronoamperometric curves of<br>
ution at 0.6 V for 3600 s; (F)  $\frac{260}{200}$   $\frac{260}{3600}$   $\frac{350}{3500}$   $\frac{30}{3500}$   $\frac{60}{3500}$   $\frac{60}{3500}$   $\frac{60}{3500}$   $\frac{100}{3500}$   $\frac{100}{3500}$   $\frac{100}{3500}$   $\frac{100}{3500}$   $\frac{100}{3500}$   $\frac{100}{3500}$   $\frac{100}{3500}$   $\frac{100}{3500}$  nograms of Pt-Fe-P and Pt/C catalysts for methanol oxidation<sup>[27]</sup>.<br>nethanol electro-oxidation; (E) Chronoamperometric curves of<br>ution at 0.6 V for 3600 s; (F) CO<sub>46</sub> stripping voltammograms<br>H<sub>2</sub>SO<sub>4</sub> solution<sup>[20]</sup>, (col tograms of Pt-Fe<sub>3</sub>P and Pt/C catalysts for methanol oxidation<sup>1271</sup>.<br>
Interhanol electro-oxidation; (E) Chronoamperometric curves of<br>
ution at 0.6 V for 3600 s; (F) CO<sub>as</sub> stripping voltammograms<br>
H<sub>2</sub>SO<sub>4</sub> solution<sup>1291</sup> nethanol electro-oxidation; (E) Chronoamperometric curves of<br>ution at 0.6 V for 3600 s; (F)  $CO_{48}$  stripping voltammograms<br>H<sub>2</sub>SO<sub>4</sub> solution<sup>[29]</sup>. (color on line)<br>modest binding energy is beneficial to the adsorption<br>a ution at 0.0 V for 5000 s; (**r**) CO<sub>as</sub> suppoing votaminograms<br>H<sub>2</sub>SO<sub>4</sub> solution<sup>[09]</sup>. (color on line)<br>modest binding energy is beneficial to the adsorption<br>and desorption of intermediates, thus, it has received<br>large modest binding energy is beneficial to the adsorption<br>and desorption of intermediates, thus, it has received<br>large attention for water splitting reaction<sup>[46, 41]</sup>. Such<br>characters make it be a suitable platform for assis modest binding energy is beneficial to the adsorption<br>and desorption of intermediates, thus, it has received<br>large attention for water splitting reaction<sup>[46, 41]</sup>. Such<br>characters make it be a suitable platform for assis modest binding energy is beneficial to the adsorption<br>and desorption of intermediates, thus, it has received<br>large attention for water splitting reaction<sup>[40, 41]</sup>. Such<br>characters make it be a suitable platform for assis and desorption of intermediates, thus, it has received<br>large attention for water splitting reaction<sup>[40, 41]</sup>. Such<br>characters make it be a suitable platform for assisting<br>the Pt based catalysts for methanol oxidation, an large attention for water splitting reaction<sup>[40, 41]</sup>. Such<br>characters make it be a suitable platform for assisting<br>the Pt based catalysts for methanol oxidation, and it<br>has a variety of stoichiometry such as CoP and Co<sub></sub> characters make it be a suitable platform for assisting<br>the Pt based catalysts for methanol oxidation, and it<br>has a variety of stoichiometry such as CoP and Co<sub>2</sub>P.<br>For example, Co<sub>2</sub>P supported on graphitized carbon<br>fabr the Pt based catalysts for methanol oxidation, and it<br>has a variety of stoichiometry such as CoP and Co<sub>2</sub>P.<br>For example, Co<sub>2</sub>P supported on graphitized carbon<br>fabricated by an ion-exchange method was employed<br>to anchor has a variety of stoichiometry such as CoP and Co<sub>2</sub>P.<br>For example, Co<sub>2</sub>P supported on graphitized carbon<br>fabricated by an ion-exchange method was employed<br>to anchor the Pt nanoparticles<sup>[42]</sup>; compared to the<br>commercial



of PtRu-CoP/C-40 % catalyst exposed to 0.5 mol $\cdot$ L<sup>-1</sup> methanol oxidation to final CO<sub>2</sub> products (Figure 3)

**THE CONSERVANT CONSERVATION** (Color and PtRu-CoP/C-40% eatalyst and showed catalysts and significant and the PtRu based catalysts at 50 mV is in additional performance care of Co.P.C, commercial PHC, PHCfree, and PtCo-P/ **Example 11.1**<br> **Example 11.1 Example 12.1 Consumer the first 2 Consumer the first 2 Consumer the first 2 The first 2 The first 2 The first 2 Consumer the first 2 The first 2 The first 2 Consumer the EXECUTE:**<br> **AN ARGO THE CONSTRANT CONSTRANT CONSTRANT TO THE CONSTRANT CONSTRANT TO THE CONSTRANT CONSTRANT TO THE CONSTRANT CONSTRANT CONSTRANT TO THE CONSTRANT CONSTRANT TO THE CONSTRANT CONSTRANT CONSTRANT CONSTRANT C Wavenumber** (fcm<sup>1</sup>)<br> **Wavenumber** (fcm<sup>1</sup>)<br> **Figure** 3 (A) Cyclic volume<br> **Figure** 3 (A) Cyclic evaluations of Co, P/C, commercial Pt/, Pc/Crefo^s and (C) discharge curves at 8 noV (s0<sup>-c</sup>) for fu-<br>
electiopics<sup>10</sup>. (B) **Eigure 3** (A) Cyclis voltammetric curves of Co<sub>2</sub>PC, commercial PeC, PeCfree, and Pr-Co<sub>2</sub>PC catalysts at 50 mV·s<sup>+</sup> in acidic<br>electrolytes<sup>52</sup>: (0) Power-density eurose for the lectle semploying PHtu-Co<sup>2</sup>PC-40% commerc electrolytes<sup>(19</sup>; (B) Power-density curves for fuel cells employing PIRu-CoP/C-40% and (C) discharge curves at 0.3 V (50 °C) for fu-<br>election-genetical CoPC-40%, commercial PREW-C-M and PRu-CoP/C-40% and the media catalys al cells employing PHxa-CaP/C-40% commercial PRkuC-JM and PRkuC-H as anode estalysts<sup>101</sup>. The multi-step attennessed infarred backgrotion spectroscopic curves of D) the PtC-OF/C decreased particle and increase of Dark Cflectance surface-enhanced infrared absorption spectroscopic curves on (D) the PtC-JM and (F) the PtCOPC electrodes, and dis-<br>charge curves (F) at 0.3 V (70 °C) for fletal si employing different catalysts<sup>193</sup>. (color on charge curves (F) at 0.3 V (70 °C) for fuel cells employing different catalysts<sup>191</sup>. (color on line)<br>performance was even higher than the power density that the presence of CoP mitigated the losses of Pt<br>offered by the s performance was even higher than the power density<br>offered by the state-of-the-art commercial PR&u/C and Ru during the fitel cells operation compared to<br>catalyst at 70 °C (63.1 mW · cm<sup>-3</sup>). The stability of the the PR&u/ performance was even higher than the power density<br>of the the presence of CoP mitigated the losses of Pt<br>offered by the state-of-the-art commencial PRuCC and Ru during the fiel elects operation compared to<br>catalyst at 70 offered by the state-of-the-art commercial PRu/C and Ru during the fuel cells operation compared to catalyst at 70°C (63.1 mW·cm<sup>3</sup>). This tsubiti y of the PRR/C catalyst; the Coclement was not found in eat<br>alyst at 70°C eatalyst at 70 °C (63.1 mW·cm<sup>-</sup>). The stability of the **PRRuC** catalyst; the Co element was not found in<br>catalyst was evaluated when discharged at 0.3 V for the cyled methanol solution with the detection limit<br>12 h at 50 caulayst was evaluated when discharged at 0.3 V for<br>
Le byckle methanol solution with the detection limit<br>
12 h at 50 "C by comparing it to the PRRu based cata-<br>
by this first first confirmed the cocelent<br>
tysts (Figure 3 12 h at 50 °C by comparing it to the PtRu based cata-<br>
of 0.001 ppb. This further confirmed the excellent<br>
type of PRu-CoP/C-40% catalysts decreased significantly gerat application prospects in DMFC. The largely im-<br>
in t lysls (Figure 3(C)). It was found that the power densi-<br>stability of PIRu-CoP/C-40% eatalyst and showed<br>on the FRu based catalysts decreased significantly great application prospects in DMFC. The largely im-<br>in the first b The cycle of Columbia and the cycle of Columbia and the cycle of the PRI and Ru during the full colls operation compared to<br>the cycle cycle methanol solution with the detection of the CM and CO discharge curves at 0.3 V ( of 0.001 ppb. This further confirmed the excellent Figure 1.180<br>
For  $r$  (cm<sup>-1</sup>)<sup>3</sup><br>
Figure 1.180<br>
For  $r$  (cm<sup>-1</sup>)<sup>3</sup><br>
Figure 1.180<br>
Public and Pt-Co<sub>2</sub>P/C catalysts at 50 mV·s<sup>-1</sup> in acidic<br>
u-CoP/C-40% and (C) discharge curves at 0.3 V (50 °C) for fu-<br>
ERU/C-H as anod Fraction 1.489<br>
Fraction 1.489<br>
Experimental application process in Distribution 1.290<br>
Time  $r$  (Cm<sup>11</sup>)<sup>8</sup><br>
Prospects and Pt-Co<sub>2</sub>P/C catalysts at 50 mV·s<sup>-1</sup> in acidic<br>
Ru/C-H as anode catalysts<sup>(s)</sup>. The multi-step at **Proved anti-CO** proved anti-COP/C catalyst and provided by  $\frac{1}{2}$  are  $\frac{1}{2}$  and  $\frac{1}{2}$  are  $\frac{1}{2}$  and  $\frac{1}{2$  $\frac{2}{100}$   $\frac{1}{100}$   $\frac{2}{100}$   $\frac{2}{100}$   $\frac{2}{3}$   $\frac{1}{100}$   $\frac{2}{100}$   $\frac{1}{100}$   $\frac{1}{1$ er /(cm<sup>-1</sup>) Time /(h)<br>
Time /(h)<br>
<sup>2</sup>VC, Pt/Cfree, and Pt-Co<sub>2</sub>P/C catalysts at 50 mV·s<sup>-1</sup> in acidic<br>
u-CoP/C-40% and (C) discharge curves at 0.3 V (50 <sup>v</sup>C) for fu-<br>
Ru/C-H as anode catalysts<sup>159</sup>. The multi-step atten PtC, PtCfree, and Pt-Co<sub>2</sub>P/C catalysts at 50 mV · s<sup>1</sup> in acidic<br>u-CoP/C-40% and (C) discharge curves at 0.3 V (50 °C) for fu-Ru/C-H as anode catalysts<sup>[50]</sup>. The multi-step attenuated total re-<br>on (D) the PtC-JM and (E) u-CoP/C-40% and (C) discharge curves at 0.3 V (50 °C) for fu-Ru/C-H as anode catalysts<sup>[35]</sup>. The multi-step attenuated total re-<br>on (D) the Pt/C-JM and (E) the Pt-CoP/C electrodes, and dis-<br>atalysts<sup>[35]</sup>. (color on line Ru/C-H as anode catalysts<sup>[61]</sup>. The multi-step attenuated total re-<br>on (D) the Pt/C-JM and (E) the Pt-CoP/C electrodes, and dis-<br>atalysts<sup>[63]</sup>. (color on line)<br>that the presence of CoP mitigated the losses of Pt<br>and Ru on (D) the PtC-JM and (E) the Pt-CoP/C electrodes, and dis-<br>atalysts<sup>[05]</sup>. (color on line)<br>that the presence of CoP mitigated the losses of Pt<br>and Ru during the fuel cells operation compared to<br>the PtRu/C catalyst; the C atalysts<sup>183</sup>. (color on line)<br>that the presence of CoP mitigated the losses of Pt<br>and Ru during the fuel cells operation compared to<br>the PtRu/C catalyst; the Co element was not found in<br>the cycled methanol solution with that the presence of CoP mitigated the losses of Pt<br>and Ru during the fuel cells operation compared to<br>the PtRu/C catalyst; the Co element was not found in<br>the cycled methanol solution with the detection limit<br>of 0.001 pp that the presence of CoP mitigated the losses of Pt<br>and Ru during the fuel cells operation compared to<br>the PtRu/C catalyst; the Co element was not found in<br>the cycled methanol solution with the detection limit<br>of 0.001 pp and Ru during the fuel cells operation compared to<br>the PtRu/C catalyst; the Co element was not found in<br>the cycled methanol solution with the detection limit<br>of 0.001 ppb. This further confirmed the excellent<br>stability of the PtRu/C catalyst; the Co element was not found in<br>the cycled methanol solution with the detection limit<br>of 0.001 ppb. This further confirmed the excellent<br>stability of PtRu-CoP/C-40% catalyst and showed<br>great applicati the cycled methanol solution with the detection limit<br>of 0.001 ppb. This further confirmed the excellent<br>stability of PtRu-CoP/C-40% catalyst and showed<br>great application prospects in DMFC. The largely im-<br>proved anti-CO of 0.001 ppb. This further confirmed the excellent<br>stability of PtRu-CoP/C-40% catalyst and showed<br>great application prospects in DMFC. The largely im-<br>proved anti-CO poisoning ability with the presence of<br>CoP in the Pt-C stability of PtRu-CoP/C-40% catalyst and showed<br>great application prospects in DMFC. The largely im-<br>proved anti-CO poisoning ability with the presence of<br>CoP in the Pt-CoP/C catalyst was previously ob-<br>served by *in-situ* 

 $\# \# \langle J. \text{Electrochem.} \rangle$  2022, 28(1), 2106211 (8 of 12)<br>
nanoparticles over carbon nanotubes were fabricated catalytic ability. The theoretical calculation indicates<br>
and further used as a support to grow the Pt nanopar-<br>
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dicties<sup>141</sup>, and the high catalytic activit manoparticles over carbon nanotubes were fabricated catalytic ebility. The theoretical calculation indicates<br>and further used as a support to grow the Pt nanopar-<br>that Pt-MoP had neither strong nor weak methanol<br>ticles<sup>(4</sup> manoparticles over carbon nanotubes were fabricated catalytic ability. The theoretical calculation indicates<br>and tirtles used as a support to gove the Pt nanopar-<br>that Pt-MoP had neither strong nor weak methanol<br>ticles<sup>ta</sup> and further used as a support to grow the Pt nanopar-<br>
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that Pt-MoP had neither strong nor weak methanol<br>
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that Pt-MoP had neither strong nor weak methanol<br>
adsorption energy, which facilitated the charge trans-<br>
fer and electrooxidation of meth  $28(1)$ ,  $2106211$  (8 of 12)<br>catalytic ability. The theoretical calculation indicates<br>that Pt-MoP had neither strong nor weak methanol<br>adsorption energy, which facilitated the charge trans-<br>fer and electrooxidation of met  $(28(1), 2106211 \ (8 \text{ of } 12))$ <br>catalytic ability. The theoretical calculation indicates<br>that Pt-MoP had neither strong nor weak methanol<br>adsorption energy, which facilitated the charge trans-<br>fer and electrooxidation of met 28(1), 2106211 (8 of 12)<br>
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e-mentioned TMPs promoters, tubes supported Pt nanoparticles showed high eatalytis assing MoP, WP, Cu<sub>b</sub>P as co-<br>
ic activity due to the interaction bet e above-mentioned TMPs promoters, tubes supported Pt nanoparticles showed high catalyties activity<br>
reproves using MoP, WP, Cu<sub>B</sub>P as co-<br>
i catrivity dat the interaction between Pt and MoP,<br>
inprove the catalytic activit some reports using MoP, WP, Cu<sub>B</sub>P as co-<br>
to actuvity due to the interaction between Pt and MoP,<br>
to improve the catalytic activity of Pt in and the uniform dispersion of Pt nanoparticles<sup>[69</sup>. Mo-<br>
to improve the actalyt 电化学(*J. Electrochem.*) 2022, 28(1), 2106211 (8 of 12)<br>tubes were fabricated catalytic ability. The theoretical calculation indicates<br>grow the Pt nanopartiant Pt-MoP had neither strong nor weak methanol<br>activity and stabi



 $\# \# \# (L \: \text{Electrochem.})$  2022, 28(1), 2106211 (9 of 12)<br>were uniformly dispersed over the support, which eff-<br>iciently increased the Pt active site utilization, and<br>the support of Pt active phase over their<br>the lowest onset p  $\text{t}E\#(J. Electron.)$ <br>  $\text{t}E\#(J. Electron.)$  2022, 28(1), 2106211 (9 of 12)<br>
were uniformly dispersed over the support, which eff-<br>
iciently increased the Pt active site utilization, and<br>
the deposition of Pt active phase over their<br> the lettrochem.) 2022, 28(1), 2106211 (9 of 12)<br>were uniformly dispersed over the support, which eff-<br>iciently increased the Pt active site utilization, and<br>the lowest onset potential was observed both in meth-<br>surface; a **19/2\*** (*J. Electrochem.*) 2022, 28(1), 2106211 (9 of 12)<br>were uniformly dispersed over the support, which eff-<br>iciently increased the Pt active site utilization, and<br>TMPs and the deposition of Pt active phase over their **EVALUATE 19**<br> **EVALUATE 1**  $\pm \frac{\text{Re}}{\text{E}}(I, \text{Electrochem.}) 2022, 28(1), 2106211 (9 of 12)$ <br>were uniformly dispersed over the support, which eff-<br>incently increased the Pt active site utilization, and the amost of Pt active phase over their<br>the lowest onset  $\mathbb{E}/\mathbb{E}/(L\ker\{m\}$ <br>were uniformly dispersed over the support, which eff-<br>on two separated steps, namely the fabrication of the<br>iciently increased the Pt active site utilization, and TMPs and the deposition of Pt acti

From the total control of the simulation and the stationary intersectives<br>
in conclusion, the largely improved eatalyie per-<br>
for the halvic process, and the catalytic meteorations are for nethanol oxidation by adding TMP In conclusion, the largely improved catalytic per-<br>
in conclusion by adding TMPs in catalytic process, and the catalytic mechanisms might<br>
the Pr eatalyts was evidenced by the examples aum-<br>
the Pr eatalytic ability conduc Iomance for methanol oxidation by adding IMPs ni<br>
the Predatyles was evidenced by the examples sum-<br>
the Predatyles was evidenced by the examples sum-<br>
the Predatyles ters end more than the profession for the surface endi the Pr catation approach by the example source and the branching the prediction by precisely and measurements. Furthermore, the hybrid catalytic system showed much better entalytic activity and an-<br>marized in Table 1. All methodology. En showed much better catalytic activity and an-<br>
Co poisoning ability compared to the catalytis system can dimorphology would be helpful to maxi-<br>
The current report and the results and the current report and the current tr-OD possoming ability compared to the catalytisty-still continue there are the external to the content of the terms of the presence of TMPs. The roles of the <sup>T</sup> model catalysts should be tested in the real fuel cells.<br>T Em without the presence of IMPs and he design-<br>the exact propose of IMPs in the catalysts system can be described in<br>
TMPs in the catalysts system can be described in<br>
TMPs in the catalysts system can be described in<br>
The TMPs in the catalysts system can be essented in the column the extension of the strength catalysts were tested in the ford external terms of the electronic structure modification of the commercial state-of-the-art catalytis, some ef-<br>sites growth and dispersion, the water activation in-<br>sites growth and dispersion, the water activation in-<br>tions in sta active Pt centers, the absorbing sites for Pt active<br>sites growth and dispersion, the water activation in-<br>sites growth and dispersion, the water activation in-<br>the fuel cells. Therefore, therefore, therefore, complementat

steel growth and daspersion, the water activation in-<br>the is still required towards the membrane electrode<br>deaced by the exypthic property as well as the bifunc-<br>tional catalytic mechanisms synergistically catalyzing<br>fore, duced by the exyphilic property as well as the brithme-<br>the catalyst layer optimization, etc. There-<br>the reaction. To increase the synergistic interaction<br>the reaction. To increase the synergistic interaction<br>destanding of tronal catalytic mechanisms sypergratically catalytical productional contents. Sure a term of the current of the mechanism of catalytic mechanism with novel lective to the mechanism of the section of the properties of the the reacton. To merease the synegotic interesting of catalytic mechanism with novel tech-<br>between the TMPs promoter and Pt hased active<br>sites, some fabrication approaches by increasing the<br>ristics, some fabrication approac

High catalytic performance was observed for PicC-Cu<sub>3</sub>P<br>
The system, on the system of the signal defection of the incircular increased the Pt active site utilization **EVALUATION CONTIVE EXAMORET (EXAMORET AND SOLUTE AT ALT ACTES CONDUCT THE CONDUCT THE CONDUCT THE CO EVALUATION**<br>
Were uniformly dispersed over the support, which eff-<br>
on two separated steps, namely the fabrication of the<br>
cicienty increased the Pt active site utilization, and TMPs and the deposition of Pt active phase  $#R# (J. Electrochem.) 2022, 28(1), 2106211 (9 of 12)$ were uniformly dispersed over the support, which eff-<br>on two separated steps, namely the fabricaticiently increased the Pt active site utilization, and TMPs and the deposition of Pt **EVALUATION**<br> **EVALUATION** In conclusion, the largely improved catalytic perthe the method of the method of the conduction by dispersed over the support, which eff-<br>on two separated steps, namely the fabrication of the<br>iciently increased the Pt active site utilization, and<br>TMPs and the deposition  $+0.2\%$ <br>
were uniformly dispersed over the support, which eff-<br>
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icriticaly increased to the the catalystic unitarial, were uniformly dispersed over the support, which eff-<br>
iciently increased the P1 active site utilization, and<br>
TMPs and the deposition of P1 active phase over their<br>
the holvest onset potential was observed both in meth-<br> we unmining using the activity interactions of the mathematic steps, hardward with the presence of TMPs and the catalytic system can be conductivity and dispersion.<br>
Here the the two states of the catalytic activity and t EVERTON TREAT THE WAT CONDIGITED TO THE THE COLOR TO THE THE CONDIGITED THE THE THE CONDIGITED THE THE COLOR COLOR OF THE COLOR COLOR THE COL the above the mode of the methanological with the content with the content of the called since the extremely same that the content of the interaction and contentius and order of Pt for methanol oxidation<sup>138</sup>. He amount a and when the catalytic methanol oxidation in the comparison of the comparison of the catalytic system showed in the catalytic system of the composite catalytic system control and not fully make use of the promotion offer t Fremshes, to easy was several as an exercise of the material and vectoric of the form the model of the electronic control and vector of the form the electronic electronic control and the electronic electronic control of t From the three measures of TMPs. The absorber and the search with the effect of TMPs,<br>the center of the composite catalysts was probed and the fully make use of the promotion effect of TMPs.<br>high catalytic performance was or equivate Causty was phonosized in the conservation in the proposition reaction. The meta-<br>endotropic conservation of the endotropic and the meta-<br>site disperse activate to the ideal composition ratio and Ture construct measure promundule was voncedured to the case<br>of the theories of the theories of the deteroio effect, and bifunctional mechanism in-<br>tive sites and TMPs promoters. Moreover, to elean-<br>duced between Cu<sub>p</sub>P and Pt.<br>To **Conc** by eating the three than comparation ratio and the best<br>be electronic effect, and bifunctional mechanism increases and TMPs promoters. Moreover, to clear<br>dueed between Cu<sub>F</sub>P and Pt.<br>
In conclusions **and Perspectives** sym the cuclum orientation of the decoration of the syntem of the syntem of the syntem of the syntem syntem (syntem syntem). To **Conclusions and Perspectives** system, some in situ spectoscopic studies might be the ln conclusio **EXECUTE THE SET THE RECORDING THE SET THE SE**  $(28(1), 2106211 (9 of 12))$ <br>on two separated steps, namely the fabrication of the<br>TMPs and the deposition of Pt active phase over their<br>surface; and the carbon support was mixed with the<br>TMPs by increasing the conductivity an  $(28(1), 2106211 (9 of 12))$ <br>on two separated steps, namely the fabrication of the<br>TMPs and the deposition of Pt active phase over their<br>surface; and the carbon support was mixed with the<br>TMPs by increasing the conductivity an  $28(1)$ ,  $2106211$  (9 of 12)<br>on two separated steps, namely the fabrication of the<br>TMPs and the deposition of Pt active phase over their<br>surface; and the carbon support was mixed with the<br>TMPs by increasing the conductivi  $(28(1), 2106211 (9 of 12))$ <br>on two separated steps, namely the fabrication of the<br>TMPs and the deposition of Pt active phase over their<br>surface; and the carbon support was mixed with the<br>TMPs by increasing the conductivity an  $(28(1), 2106211)$  (9 of 12)<br>
on two separated steps, namely the fabrication of the<br>
TMPs and the deposition of Pt active phase over their<br>
surface; and the carbon support was mixed with the<br>
TMPs by increasing the conduct  $28(1)$ ,  $2106211$  (9 of 12)<br>on two separated steps, namely the fabrication of the<br>TMPs and the deposition of Pt active phase over their<br>surface; and the carbon support was mixed with the<br>TMPs by increasing the conductivi  $(28(1), 2106211 (9 of 12))$ <br>on two separated steps, namely the fabrication of the<br>TMPs and the deposition of Pt active phase over their<br>surface; and the carbon support was mixed with the<br>TMPs by increasing the conductivity an  $(28(1), 2106211 (9 of 12))$ <br>on two separated steps, namely the fabrication of the<br>TMPs and the deposition of Pt active phase over their<br>surface; and the carbon support was mixed with the<br>TMPs by increasing the conductivity an  $(28(1), 2106211 (9 of 12))$ <br>on two separated steps, namely the fabrication of the<br>TMPs and the deposition of Pt active phase over their<br>surface; and the carbon support was mixed with the<br>TMPs by increasing the conductivity an  $28(1)$ ,  $2106211$  (9 of 12)<br>on two separated steps, namely the fabrication of the<br>TMPs and the deposition of Pt active phase over their<br>surface; and the carbon support was mixed with the<br>TMPs by increasing the conductivi . 28(1), 2106211 (9 of 12)<br>
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surface; and the carbon support was mixed with the<br>
TMPs by increasing the conducti  $\frac{1}{28(1)}$ ,  $\frac{2106211}{9612}$  of 12)<br>on two separated steps, namely the fabrication of the<br>TMPs and the deposition of Pt active phase over their<br>surface; and the carbon support was mixed with the<br>TMPs by increasing the  $(28(1), 2106211 (9 of 12))$ <br>on two separated steps, namely the fabrication of the<br>TMPs and the deposition of Pt active phase over their<br>surface; and the carbon support was mixed with the<br>TMPs by increasing the conductivity an  $(28(1), 2106211 (9 of 12))$ <br>on two separated steps, namely the fabrication of the<br>TMPs and the deposition of Pt active phase over their<br>surface; and the carbon support was mixed with the<br>TMPs by increasing the conductivity an  $(28(1), 2106211 (9 of 12))$ <br>on two separated steps, namely the fabrication of the<br>TMPs and the deposition of Pt active phase over their<br>surface; and the carbon support was mixed with the<br>TMPs by increasing the conductivity an **Example 18**<br>
In two separated steps, namely the fabrication of the<br>
TMPs and the deposition of Pt active phase over their<br>
surface; and the carbon support was mixed with the<br>
TMPs by increasing the conductivity and disper on two separated steps, namely the fabrication of the<br>TMPs and the deposition of Pt active phase over their<br>surface; and the carbon support was mixed with the<br>TMPs by increasing the conductivity and dispersion.<br>Therefore, TMPs and the deposition of Pt active phase over their<br>surface; and the carbon support was mixed with the<br>TMPs by increasing the conductivity and dispersion.<br>Therefore, the interaction and electronic effect of Pt<br>active sit surface; and the carbon support was mixed with the<br>TMPs by increasing the conductivity and dispersion.<br>Therefore, the interaction and electronic effect of Pt<br>active sites and TMPs will be reduced, which might<br>not fully mak TMPs by increasing the conductivity and dispersion.<br>Therefore, the interaction and electronic effect of Pt<br>active sites and TMPs will be reduced, which might<br>not fully make use of the promotion effect of TMPs.<br>Attention th Therefore, the interaction and electronic effect of Pt<br>active sites and TMPs will be reduced, which might<br>not fully make use of the promotion effect of TMPs.<br>Attention thus might be directed to the microstruc-<br>ture constru active sites and TMPs will be reduced, which might<br>not fully make use of the promotion effect of TMPs.<br>Attention thus might be directed to the microstruc-<br>ture construction with the efficient interfaces of Pt<br>active sites not fully make use of the promotion effect of TMPs.<br>Attention thus might be directed to the microstruc-<br>ture construction with the efficient interfaces of Pt<br>active sites and TMPs promoters. Moreover, to clear-<br>ly understa Attention thus might be directed to the microstruc-<br>ture construction with the efficient interfaces of Pt<br>active sites and TMPs promoters. Moreover, to clear-<br>ly understand the promotion effect of TMPs in the<br>system, some ture construction with the efficient interfaces of Pt<br>active sites and TMPs promoters. Moreover, to clear-<br>ly understand the promotion effect of TMPs in the<br>system, some in situ spectroscopic studies might be<br>helpful to pr active sites and TMPs promoters. Moreover, to clear-<br>ly understand the promotion effect of TMPs in the<br>system, some in situ spectroscopic studies might be<br>helpful to probe the catalytic intermediates during the<br>catalytic p ly understand the promotion effect of TMPs in the<br>system, some in situ spectroscopic studies might be<br>helpful to probe the catalytic intermediates during the<br>catalytic process, and the catalytic mechanisms might<br>be further system, some in situ spectroscopic studies might be helpful to probe the catalytic intermediates during the catalytic process, and the catalytic mechanisms might be further understood with the help of electrochemical measu helpful to probe the catalytic intermediates during the catalytic process, and the catalytic mechanisms might be further understood with the help of electrochemical measurements. Furthermore, the hybrid catalyst rational d catalytic process, and the catalytic mechanisms might<br>be further understood with the help of electrochemi-<br>cal measurements. Furthermore, the hybrid catalyst<br>rational design and fabrication by precisely tuning the<br>structur cal measurements. Furthermore, the hybrid catalyst<br>rational design and fabrication by precisely tuning the<br>structure and morphology would be helpful to maxi-<br>mize the catalytic ability. Finally, the newly devel-<br>oped catal ional design and fabrication by precisely tuning the<br>ucture and morphology would be helpful to maxi-<br>ze the catalytic ability. Finally, the newly devel-<br>ed catalysts should be tested in the real fuel cells.<br>ough some catal structure and morphology would be helpful to maxi-<br>mize the catalytic ability. Finally, the newly devel-<br>oped catalysts should be tested in the real fuel cells.<br>Though some catalysts were tested in the fuel cell de-<br>vices mize the catalytic ability. Finally, the newly devel-<br>oped catalysts should be tested in the real fuel cells.<br>Though some catalysts were tested in the fuel cell de-<br>vices with excellent catalytic performance compared<br>to th oped catalysts should be tested in the real fuel cells.<br>Though some catalysts were tested in the fuel cell de-<br>vices with excellent catalytic performance compared<br>to the commercial state-of-the-art catalysts, some ef-<br>fort is with excellent catalytic performance compared<br>the commercial state-of-the-art catalysts, some ef-<br>t is still required towards the membrane electrode<br>prication, catalyst layer optimization, etc. There-<br>e, future attentio to the commercial state-of-the-art catalysts, some ef-<br>fort is still required towards the membrane electrode<br>fabrication, catalyst layer optimization, etc. There-<br>fore, future attention can be directly paid to the un-<br>ders fort is still required towards the membrane electrode<br>fabrication, catalyst layer optimization, etc. There-<br>fore, future attention can be directly paid to the un-<br>derstanding of catalytic mechanism with novel tech-<br>niques, fabrication, catalyst layer optimization, etc. There-<br>fore, future attention can be directly paid to the un-<br>derstanding of catalytic mechanism with novel tech-<br>niques, and precise catalyst structure design and fab-<br>ricati anding of catalytic mechanism with novel tech-<br>s, and precise catalyst structure design and fab-<br>on, as well as their application in the real fuel<br>evices.<br>aration of Competing Interest:<br>e authors declare that they have no 电化学(*J. Electrochem.*) 2022, 28(1), 2106211 (9 of 12)<br>he support, which eff-<br>on two separated steps, namely the fabrication of the<br>site utilization, and TMPs and the deposition of Pt active phase over their<br>bserved both

## Note:

### Acknowledgements:

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# 磷化物助力铂基催化剂甲醇电氧化的研究进展

## 李 萌,冯立纲\*

(扬州大学化学化工学院 江苏 扬州 225002)

搞要: 过渡金属磷化物(TMP)作为一种理想的甲醇电氧化助催化剂,因其具有多功能活性位点、结构和组成可调、独特的物 理化学性质和高效的多组分问效应等优势而受到越来越多的关注。本文综述了过渡金属磷化物促进甲醇电氧化的研究进 展,包括催化剂的制备及其催化甲醇电氧化的性能评估。首先,介绍了 TMP 对催化甲醇氧化反应的促进作用,然后在正文中 讨论了基于不同金属中心的 TMP 催化剂体系的制备与性能研究。从电子效应和基于双功能催化机制的亲氧性来看,TMPs 对催化甲醇氧化有明显的促进作用。最后,我们讨论了在催化剂理性设计及其催化机理探索和燃料电池装置应用中应注意 的问题和挑战,希望对新型催化剂体系的设计和制备有一定的指导意义。

关键词: 过渡金属磷化物;甲醇氧化反应;促进剂;电催化