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# ENDNOTE:coral

# [Pt nanowires-Pt "nanowires arrays"]-分类-相关-绪论要用

主要看三个：1.珊瑚状前言如何写；2.刘智的cec如何引入；3.刘智大论文中第五章写了些什么

## [1] H. Xu, F. Ren, B. Yan, J. Wang, S. Li, Y. Du, Superior liquid fuel oxidation electrocatalysis enabled by novel one-dimensional AuM (M = Pt, Pd) nanowires, Journal of Electroanalytical Chemistry, 2018, 811: 37-45.

1. Introduction  
Preeminent energy density and perfect environmental benignity  
make fuel cells an ideal energy storage and conversion device [1]. And  
the sustainable and clean energy generated through the typical electrochemical processes, for which the reaction happened between a liquid fuel at the anode and molecular oxygen at the cathode [2,3].  
【燃料电池商业化阻碍，要求低成本催化剂】

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However, one of the major obstructions facing the large-scale commercialization of fuel cell is the requirement of cost-efficient catalysts  
for the electrooxidation reaction [4].

【Pt and Pd由于高活性在燃料电池中至关重要，缺点：资源少，耐毒化性能差】

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Till now, Pt and Pd undoubtedly  
play the crucial roles in the ongoing commercial development of fuel  
cells for their extremely superior electrocatalytic activity and durability, while both the scare natural abundance and poor anti-poisoning  
ability impose major limitations on its role in future electrocatalyst  
application [5 –7].

【Pt or Pd目标或挑战：用量少，高活性，耐毒化性】

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To this end, engineering the electrocatalysts with less  
usage of noble metal Pt or Pd but greatly enhanced electrocatalytic  
activity and superior CO-tolerance has attracted increasing research  
notices [8,9].

【】

Au, emerged as an interesting catalyst ligand had attracted an increasing research notice due to the fact that Au at the  
nanoscale could show a battery of mesmerizing features, such as its  
size-related electronic, optical and magnetic effect [10,11]. In addition,  
Au was also not prone to be poisoned by CO, therefore, it shed light on  
the use as a promising component of catalyst hybrids [12 –15].  
【催化性能依赖于形貌】

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On the other hand, apart from the influence of compositions, the

catalytic performances of electrocatalysts are also morphology-dependent [16,17]. 【调控形貌来优化面积，是提高性能的有效方法】

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In general, tuning or optimizing the exposed surface active area via regulating the shape of the catalyst is deemed to be an effective approach for improving the electrocatalytic performances.

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In this respect, many fascinating nanostructures such as core-shell  
[18,19], dendrite [20], nanowire [21,22], nanocube [23] and some  
other nanocatalysts with unique shapes [24] have been developed. 【贵金属最大化利用，丰富的活性面积，催化剂显示了高性能】

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Due  
to the fact that the maximized utilization of noble metals and abundant  
active surface areas available for small organic molecules, all of these  
electrocatalysts with unique morphologies apparently exhibit excellent  
electrocatalytic performances towards liquid fuel oxidation [25,26].

【多成分的、大的活性面积的，形貌可控催化剂合成，对高性能催化剂至关重要】

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Therefore, shape-controlled synthesis of multicomponent metal nanocrystals bounded with abundant exposed active surface areas is of vital  
significance in the design and synthesis of high-activity catalysts [27].

【策略：构建形貌和结构，提高活性，稳定性】

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In view of this, another popular technique for synthesizing typical Pt or Pd-based electrocatalysts with both elevated electrocatalytic activity  
and durability is to construct the nanocatalysts with desirable morphology and structure [28].

【！！！优势：由于纳米线各向异性，大的界面面积，自支持特性，提高了电荷转移，利于反应物和纳米线结合， 最终提高活性和稳定性】

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Among multitudinous structures, owing to  
its inherent anisotropy, larger interfacial area and self-supported  
properties [29], one-dimensional (1D) nanowires (NWs) can not only  
enhance charger transfer [30] but also facilitate the binding between  
reactant and NWs, ultimately lead to the superior catalytic activity and  
durability [31].  
【】In accordance with this guideline, if we take the advantages of both

composition and morphology to engineer the PtAu and PdAu intermetallic phases nanocatalysts with desirable nanostructures, it will be  
extremely favorable for greatly enhancing the catalytic performances of  
electrooxidation reaction of liquid fuel [32,33].  
【！！！本文，无模板法被报道，设计纳米线，温和条件，覆盖剂协助】

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Herein, a template free strategy has been reported for engineering a novel class of ultrafine 1D PtAu and PdAu alloy NWs at a milder condition with the assistance of dual capping agents of polyvinylpyrrolidone (PVP) and cetyltrimethylammonium bromide (CTAB).【本文，！！！纳米线形成源于颗粒的定向粗化】

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Impressively, the formation of these unique 1D alloy NWs may originate from the directional coalescence of the as-produced nanoparticles.  
 【本文，由于纳米线大的面积，合金电子效应，合金纳米线显示了超高质量活性，】

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Owing to the abundant surface active areas derived from the fascinating 1D NWs structure, as well as the alloy and electronic effects between different metals, both the as-obtained 1D PtAu and PdAu NWs with  
optimum compositions exhibited unprecedentedly high electrocatalytic  
performances with the mass activities of 7.81 and 5.72 A mgPt− 1, 6.55  
and 4.52 A mgPd− 1 towards ethylene glycol (EG) and glycerol oxidation, respectively. 【本文，CA,CV表明合金纳米线高稳定性】

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In addition, the chronoamperometry (CA) and successive cyclic voltammetry (CV) of 500 cycles have revealed that the attractive 1D PtAu and PdAu NWs possessed the extremely superior  
long-term stability. 【本文，相信方法可以用于未来金属制备，制备的催化剂可很好用于燃料电池】

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We confirmedly believed that this proposed plot  
may be significant for the fabrication and modification for future metallic catalysts and the as-prepared unique 1D NWs electrocatalysts with  
outstandingly excellent electrocatalytic performances can be well applied for boosting the development fuel cells【】

## [2] C. Wang, Y. Zhang, Y. Zhang, P. Xu, C. Feng, T. Chen, T. Guo, F. Yang, Q. Wang, J. Wang, M. Shi, L. Fan, S. Chen, Highly Ordered Hierarchical Pt and PtNi Nanowire Arrays for Enhanced Electrocatalytic Activity toward Methanol Oxidation, ACS Applied Materials and Interfaces, 2018, 10: 9444-9450.

1. INTRODUCTION  
【由于高能量，低温运行，甲醇丰富，液态燃料处理方便，燃料电池具有很好应用前景】

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Direct methanol fuel cells (DMFCs) have gained extensive  
attention as a promising technology in powering portable  
electronic devices due to the high energy density of methanol,  
low operating temperature, the abundance of methanol, and  
ease of handling liquid fuels.1 −7 【Pt被广泛使用，资源少，高成本，易毒化】

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Pt-based nanomaterials have  
been used extensively as the anode catalysts for methanol  
oxidation.8 However, the widespread applications of DMFCs  
have been hampered by the low natural abundance, high costs,  
and susceptibility to poisoning of Pt.9 【大量工作致力于Pt，成分，形貌，维度构建，为提高利用率，性能】

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Thus, substantial efforts  
have been devoted to the structural engineering of nanostructured Pt catalysts, in particular, with regard to  
composition, morphology, and dimension, so as to improve  
the utilization efficiency of Pt and enhance the electrocatalytic  
performance.10−12【Pt提策略：高表面积、面积体积比】

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Toward this end, one effective approach is to synthesize Pt-based catalysts with high surface areas and  
surface-to-volume ratios.13−16【一次列Pt纳米结构，球颗粒，纳米簇，纳米线，形状，枝晶，被分散在基体上】

【一次列Pt纳米结构，球颗粒，纳米簇，纳米线，形状，枝晶，被分散在基体上】

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In fact, in recent studies, a wide range of Pt-based nanostructures have been produced, including spherical particles, nanoclusters, nanorods/wires,  
star-shaped particles, branched multipods, dendritic nanogarlands, etc.,17−28 and dispersed on appropriate supporting  
materials.29 −33 【颗粒被分散在基体上，这些质轻、高表面积基体有利于表面无障碍和电子转移动力学】

【颗粒被分散在基体上，这些质轻、高表面积基体有利于表面无障碍和电子转移动力学】

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For instance, Pt-nanoparticle (NP) catalysts  
have been deposited on carbon nanotubes, carbon fibers,  
fullerene, graphene, and nanoporous graphitic carbon materials,8,16,21,28,34−37 and the use of these lightweight, high-surface area catalyst supports leads to good dispersion of the Pt NPs,  
which facilitates surface accessibility and electron-transfer  
kinetics.【分级结构将提高表面积】

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The effective electrochemical surface areas may also be enhanced by the formation of hierarchical platinum  
nanostructures. 【有序纳米线阵列，使用AAO模板，孔径和管道长度可调，介孔纤维，电化学还原】

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For instance, ordered nanowire arrays have  
been readily prepared by utilizing anodic aluminum oxide  
(AAO) template with tunable pore diameter and channel  
length, and mesoporous Pt fibers have been prepared by  
photoreduction or electrochemical reduction of metal precursors dissolved in the aqueous solution.38,39 【大量边角Pt原子提高活性】

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The formation of  
a large number of edge and corner Pt atoms plays an essential  
role in enhancing the electrocatalytic activity toward methanol  
oxidation.【相比单金属易毒化，合金化提高抗毒化】

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In addition, it has been demonstrated that in contrast to  
monometallic Pt catalysts, which are prone to poisoning during  
methanol oxidation reaction, alloying of Pt with a second  
transition metal signifi cantly can enhance the resistance against  
poisoning species.40 −47 【】 For instance, marked enhancement has  
been observed with Pt −Ru and Pt −Pd alloys, and cocatalysts,  
such as Ni, Cu, Mo and Co, actually have also been used due to  
their high abundances and low costs.46 −52 The formation of  
such Pt −M alloy structures leads to weakened Pt −CO binding  
interactions and the formation of OH species at a reduced  
potential that is reactive with intermediates on the catalyst  
surfaces.53 −55 【多元成分催化剂结合减少pt用量，提高耐毒化，提高稳定性，转换效率】

【多元成分催化剂结合减少pt用量，提高耐毒化，提高稳定性，转换效率】

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That is, the incorporation of cocatalysts reduces  
the loading of expensive Pt, enhances resistance against  
poisoning, improves catalyst stability and durability, and  
ultimately the overall energy conversion efficiency.  
【分级纳米线被制备，以。。为模板，被用于。。】

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In the present study, Pt and PtNi hierarchical nanowire  
arrays (HNWAs) were prepared by a facile procedure based on  
CdS HNWAs templates and used as effective catalysts toward  
methanol oxidation.【】 The CdS HNWAs were prepared by the  
deposition of CdS NPs into nanoporous AAO template and  
then served as a sacrificial template for the preparation of Pt or  
PtNi HNWAs. The simultaneous dissolution of CdS NPs and  
electrochemical deposition of Pt (or PtNi) HNWAs in aqueous  
solution were conducted at ambient temperature. 【本文，结构被表征，光谱测量】

【本文，结构被表征，光谱测量】

[2] C. Wang, Y. Zhang, Y. Zhang, P. Xu, C. Feng, T. Chen, T. Guo, F. Yang, Q. Wang, J. Wang, M. Shi, L. Fan, S. Chen, Highly Ordered Hierarchical Pt and PtNi Nanowire Arrays for Enhanced Electrocatalytic Activity toward Methanol Oxidation, ACS Applied Materials and Interfaces, 2018, 10: 9444-9450.

The as-prepared nanostructured Pt and PtNi HNWAs were characterized by a wide range of spectroscopic measurements.  
 【本文，电化学测试表明，相比于实心纳米线阵列，空心更高活性】

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Electrochemical measurements showed that in comparison to  
Pt solid nanowire arrays (SNWAs) that were prepared without  
the use of CdS HNWAs as sacrificial templates, Pt HNWAs  
demonstrated remarkably enhanced electrocatalytic activity for  
methanol oxidation.【本文，活性，耐毒化性进一步的提高，由于合金化】

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Further improvement of the electrocatalytic activity was achieved by the preparation of PtNi alloy HNWAs where CO poisoning of the catalysts was considerably reduced【】

## [3] E. S. Valério Neto, M. A. Gomes, G. R. Salazar-Banda, K. I. B. Eguiluz, Pt and Pt–Rh nanowires supported on carbon and SnO2:Sb nanoparticles for ethanol electrochemical oxidation in acidic media, International Journal of Hydrogen Energy, 2018, 43: 178-188.

Introduction  
Lately, there is growing concern about minimizing the damage caused by the burning of fossil fuels, which represent  
most of the world energy matrix. In this context, fuel cells  
have attracted great interest, mainly due to their high energy  
efficiency and low gas emissions [1].  
In this scenario, fuel cells appear as a short-term viable  
solution to solve the problems of clean energy generation with  
high efficiency, due to the depreciation of fossil fuels and  
increasing environmental degradation [2]. They are open  
thermodynamic systems [3] that can transform chemical

energy directly into electrical energy, releasing only CO2 and  
H2O as products when fueled with an alcohol or another  
compound containing carbon.  
Focus on developing fuel cell systems fueled with ethanol  
has emerged from the need to replace methanol, which is  
the most commonly used liquid fuel. In addition to having  
low energy density per molecule in complete oxidation (6  
ee), methanol is toxic and presents high miscibility with  
water, leading to huge environmental concerns about  
working with this alcohol. On the other hand, ethanol has a  
higher energy density per molecule in complete oxidation (12  
ee) (in comparison with methanol), can be produced directly  
and in large quantities from renewable sources, has low  
toxicity, and is more easily transported and stored. Hence,  
ethanol appears to be a good alternative for use in direct  
alcohol fuel cells [4].  
Nevertheless, the total oxidation of ethanol to CO2 is the  
major problem in the electro-catalysis of this alcohol. The  
large-scale commercialization of direct ethanol fuel cells  
(DEFCs) has been hampered by ethanol's slow and inefficient  
oxidation even with state-of-the-art catalysts [5e7]. During its  
electro-oxidation, ethanol undergoes parallel and/or consecutive reactions, which produce mainly acetaldehyde, acetic  
acid, and CO2. For each reaction path, a different number of  
electrons are consumed, which consequently decreases the  
efficiency of the process, since the higher energy density is  
only achieved when total oxidation occurs [8].  
Complete oxidation of ethanol is associated with the  
cleavage of the CeC bond of the alcohol and the formation of  
two CeO bonds that are derived from the alcohol methyl  
group. Complete oxidation is also related to the oxidation of  
CO formed from alcohol fragments. The major challenge is the  
development of catalysts that are effective in breaking the  
CeC bond at low potentials, since there is a consensus that the  
partial oxidation of ethanol dominates on most Pt electrocatalysts [8]. To overcome this barrier, the use of Pt coupled  
with one or two metals is required. Thus, Rh appears as an  
alternative for ethanol oxidation and efforts have been made  
to study this element, mainly because it is able to facilitate the  
breaking of the CeC bond and increase the yield of the CO2  
production [5e8].  
The catalysts used in fuel cells are mostly composed of  
metal and a support material, where carbon has been widely  
used as support, mainly in fuel cells that are operating at low  
temperatures. However, carbon is an inert material that  
serves only as a mechanical support and thus does not assist  
the catalytic activity of the material [9]. Thus, SnO2 has been  
suggested as a support material, mainly because of its  
chemical properties, namely its ability to adsorb OH species  
at low potential and/or induce the electronic effect with  
platinum-based catalysts [9]. These properties give SnO2 the  
ability to electrochemically oxidize CO and low molecular  
weight alcohols such as methanol and ethanol, even when it  
is used as support [8].  
Undoped SnO2 is commonly known as a poor electrical  
conductor [9,10]. On the other hand, SnO2 doped with metal  
shows higher electrochemical conductivity and better stability [11]. Thus, metal-doped SnO2 could promote the  
oxidation of low-molecular-weight alcohols more efficiently  
[11]. Hence, Sb, as doping agent on SnO2 [10e12], acts  
improving the OH species adsorption and benefiting the  
electronic characteristics of SnO2 [13], resulting on catalysts  
with greater conductivity and stability, which could be successfully applied in fuel cell systems. Furthermore,  
antimony-doped tin oxide (ATO) is stable in acidic medium,  
widely commercially available, and presents good electrochemical stability at anodic potentials [14]. 【。。被用于提高活性、稳定性】

【。。被用于提高活性、稳定性】

[3] E. S. Valério Neto, M. A. Gomes, G. R. Salazar-Banda, K. I. B. Eguiluz, Pt and Pt–Rh nanowires supported on carbon and SnO2:Sb nanoparticles for ethanol electrochemical oxidation in acidic media, International Journal of Hydrogen Energy, 2018, 43: 178-188.

Herein, ATO was  
used to improve the electrochemical activity and stability of  
the catalysts.  
【pt颗粒常用于燃料电池，不利于催化性能】

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[3] E. S. Valério Neto, M. A. Gomes, G. R. Salazar-Banda, K. I. B. Eguiluz, Pt and Pt–Rh nanowires supported on carbon and SnO2:Sb nanoparticles for ethanol electrochemical oxidation in acidic media, International Journal of Hydrogen Energy, 2018, 43: 178-188.

The catalysts most commonly used in fuel cells are in the  
form of Pt nanoparticles (zero-dimensional) structures. However, these structures exhibit some restrictions that directly  
affect their catalytic activity. 【pt颗粒缺点：大量低配位原子，表面缺陷】

【pt颗粒缺点：大量低配位原子，表面缺陷】

[3] E. S. Valério Neto, M. A. Gomes, G. R. Salazar-Banda, K. I. B. Eguiluz, Pt and Pt–Rh nanowires supported on carbon and SnO2:Sb nanoparticles for ethanol electrochemical oxidation in acidic media, International Journal of Hydrogen Energy, 2018, 43: 178-188.

Briefly, the major defects related  
to Pt nanoparticles are (i) a high number of low coordination  
atoms and (ii) surface defects [15].【控制形貌将提高性能】

【控制形貌将提高性能】

[3] E. S. Valério Neto, M. A. Gomes, G. R. Salazar-Banda, K. I. B. Eguiluz, Pt and Pt–Rh nanowires supported on carbon and SnO2:Sb nanoparticles for ethanol electrochemical oxidation in acidic media, International Journal of Hydrogen Energy, 2018, 43: 178-188.

On the other hand, controlling the material's morphology may improve the catalytic  
performance [16]. 【一维结构受到关注，由于高比表面体积，特性，可靠性稳定，活性】

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Thus, one-dimensional structures like nanowires and nanotubes have attracted interest due to their  
improved features, such as a high ratio of surface area to  
volume, giving them unique properties, excellent reliability,  
and catalytic activity [17].  
【纳米线优势，缺陷少、光滑晶面，导致好的敏感性和活性】

【纳米线优势，缺陷少、光滑晶面，导致好的敏感性和活性】

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Moreover, platinum nanowires are commonly reported as  
presenting a low number of surface defects and long segments  
of smooth crystal planes, resulting in good sensitivity and  
activity of the catalyst [18,19]. 【纳米线可以提高活性、稳定性】

【纳米线可以提高活性、稳定性】

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Furthermore, Pt or Pt-based  
nanowires could improve the activity and stability of the  
anode electrodes [20]. 【纳米线优势，各向异性，有利于电荷传递、暴露更大面积】

【纳米线优势，各向异性，有利于电荷传递、暴露更大面积】

[3] E. S. Valério Neto, M. A. Gomes, G. R. Salazar-Banda, K. I. B. Eguiluz, Pt and Pt–Rh nanowires supported on carbon and SnO2:Sb nanoparticles for ethanol electrochemical oxidation in acidic media, International Journal of Hydrogen Energy, 2018, 43: 178-188.

These structures could improve the  
efficiency of the DEFCs, mainly due to the beneficial features  
resulting from their anisotropy, facilitating electron transfer  
and exposing a greater surface area as electrochemically  
active sites [21].【纳米线结构克服颗粒的局限性】

【纳米线结构克服颗粒的局限性】

[3] E. S. Valério Neto, M. A. Gomes, G. R. Salazar-Banda, K. I. B. Eguiluz, Pt and Pt–Rh nanowires supported on carbon and SnO2:Sb nanoparticles for ethanol electrochemical oxidation in acidic media, International Journal of Hydrogen Energy, 2018, 43: 178-188.

Thus, the use of structures like nanowires  
may overcome the limitations presented by nanoparticles.

【本文，报道了纳米线被制备，支持在基体上，无活性剂和稳定剂】

【本文，报道了纳米线被制备，支持在基体上，无活性剂和稳定剂】

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Therefore, in this paper, the synthesis of platinum and  
platinum-rhodium nanowires supported on carbon powder  
and mixtures containing carbon and antimony-doped tin  
oxide (ATO) without the use of any surfactant or stabilizing  
agent is reported. 【本文，纳米线催化效率和稳定性被分析，为了发展用于阳极的催化剂】

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The efficiency of these nanowires towards  
the electrochemical oxidation of ethanol in acid media, as well  
as the stability of these catalysts, is analyzed with the aim of  
developing of catalysts that can be efficiently applied at the  
anode of a DEFC. 【】

## [4] J. X. Tang, Q. S. Chen, L. X. You, H. G. Liao, S. G. Sun, S. G. Zhou, Z. N. Xu, Y. M. Chen, G. C. Guo, Screw-like PdPt nanowires as highly efficient electrocatalysts for methanol and ethylene glycol oxidation, Journal of Materials Chemistry A, 2018, 6: 2327-2336.

1. Introduction  
With the development of human society, one of the major  
challenges is the strong demand for new resources for the  
replacement of traditional fossil fuels. In the past few decades,  
direct alcohol (methanol, ethanol, EG, glycerol, etc. ) fuel cells  
(DAFCs), serving as potential alternative power sources for  
transportation vehicles and portable electronic devices, have  
attracted enormous attention and have received extensive  
investigations.1–6【燃料电池优势、能量高、低温运行、燃料便宜，环保】

【燃料电池优势、能量高、低温运行、燃料便宜，环保】

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DAFCs hold the advantages of high energy  
density, low operating temperature, cheap liquid fuel, ease of  
handling and friendliness to the environment.7,8 However,  
【燃料电池问题，高成本，低催化效率】

【燃料电池问题，高成本，低催化效率】

[4] J. X. Tang, Q. S. Chen, L. X. You, H. G. Liao, S. G. Sun, S. G. Zhou, Z. N. Xu, Y. M. Chen, G. C. Guo, Screw-like PdPt nanowires as highly efficient electrocatalysts for methanol and ethylene glycol oxidation, Journal of Materials Chemistry A, 2018, 6: 2327-2336.

DAFCs are still far from commercial application to date mostly  
due to the high cost and unsatisfactory efficiency of the catalysts. 【Pt是优秀催化剂，由于高活性】

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During the search for high-performance catalysts for  
DAFCs, it has been found that Pt is the most promising and  
commonly used metal component owing to its high activity.9–13  
【pt昂贵，资源少，限制应用】

【pt昂贵，资源少，限制应用】

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Nevertheless, Pt is quite expensive and scarce thus limiting its widespread applications. 【】Pd based electrocatalysts have therefore attracted increasing interest because of their excellent  
activity, lower price and greater resistance to CO in comparison  
with Pt catalysts.14–16  
【活性通过电子结构或合金化，表面结构来调控】

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The catalytic ability of catalysts may be tuned either by  
altering their electronic structure (alloying or modifying with  
different elements) or by controlling their surface structure.17 【合金降低pt用量，提高性能，相比于单金属，由于电子效应】

【合金降低pt用量，提高性能，相比于单金属，由于电子效应】

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PdPt alloys can not only lower the Pt loading and thus reduce  
the cost, but can also highly improve the performance in  
comparison with the single metal Pt, because of the varying  
electronic structure induced by Pd.18,19 【大量努力致力于合成。。。，很大进步被取得，在成分和形状可控方面，文献】

【大量努力致力于合成。。。，很大进步被取得，在成分和形状可控方面，文献】

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To date, great efforts  
have been devoted to synthesizing PdPt bimetallic catalysts and  
much progress has been made in controlling the PdPt composition and shape. Koper et al. have synthesized a series of sphere  
like PdPt alloys supported on carbon black with different  
compositions and revealed that the activity of formic acid

oxidation and CO2 reduction is highly dependent on the ratio of  
Pd–Pt.20 Various well dened shapes of PdPt nanocrystals  
enclosed with low or high-index facets have been reported,  
including cube, tetrahedron, icosahedron, tetrahexahedron,  
wire, etc. 21–24 Other irregular morphologies of PdPt alloys such  
as nanoowers, nanodendrites, and networks have also been  
achieved.25–27 【纳米线受到关注，由于有优异的催化性能，文献】

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Among which, PdPt bimetallic nanomaterials with  
a 1D nanowire structure have attracted increasing research  
interest because of their exceptional catalytic properties. Adzic  
and co-workers have synthesized Pd–Pt core–shell nanowires by  
a two-step methodology involving the synthesis of Pd nanowires  
in an organic solvent and further deposition of a platinum  
monolayer shell by galvanic replacement of the UPD Cu layer.28  
PdPt alloy nanowires have been synthesized by Dong's group  
through a galvanic replacement reaction using Te nanowires as  
a sacricial template.29 Hong et al. reported a wet chemical  
route to fabricate bimetallic PdPt nanowire networks with  
tunable compositions.27 【1维纳米材料是良好催化剂，氧化还原反应，小分子，由于表面结构和成本效应，文献】

【1维纳米材料是良好催化剂，氧化还原反应，小分子，由于表面结构和成本效应，文献】

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These 1D bimetallic PdPt nanomaterials have been demonstrated to be effective catalysts for  
oxygen reduction or small organic molecule oxidation thanks to  
their surface structural and compositional effects.  
Very recently, a new class of nanowires with screw-like  
boundaries was achieved for single metal Ag, and Pt–Co and Pt–  
Cu bimetallic systems.30–32 The unique Pt based nanowires with Pt rich surfaces possess advantages of both one dimensional  
and high-index features, and thus exhibit unprecedented  
performance for electrocatalysis.31,32 【据我们所知，。螺旋状纳米线没有报道】

【据我们所知，。螺旋状纳米线没有报道】

[4] J. X. Tang, Q. S. Chen, L. X. You, H. G. Liao, S. G. Sun, S. G. Zhou, Z. N. Xu, Y. M. Chen, G. C. Guo, Screw-like PdPt nanowires as highly efficient electrocatalysts for methanol and ethylene glycol oxidation, Journal of Materials Chemistry A, 2018, 6: 2327-2336.

To the best of our knowledge, there has been no successful report on the preparation of  
Pd based screw-like nanowires so far. 【值得指出的是，纳米线被制备，大量报道湿化学法，利用模板和活性剂】

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It should also be pointed  
out that most of the reported Pd based or Pt based nanowires  
have been achieved by wet chemical methods which required  
either templates or surfactants. 【挑战：合成高指数晶面，不使用模板和有机配体】

【挑战：合成高指数晶面，不使用模板和有机配体】

[4] J. X. Tang, Q. S. Chen, L. X. You, H. G. Liao, S. G. Sun, S. G. Zhou, Z. N. Xu, Y. M. Chen, G. C. Guo, Screw-like PdPt nanowires as highly efficient electrocatalysts for methanol and ethylene glycol oxidation, Journal of Materials Chemistry A, 2018, 6: 2327-2336.

Therefore, developing an  
effective approach to synthesize PdPt nanowires enclosed with  
high-index facets without using any templates and organic  
ligands is still a great challenge. 【纳米线催化提高的本质，被完全理解，还不清楚】

【纳米线催化提高的本质，被完全理解，还不清楚】

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Besides, although bimetallic  
PdPt nanowires may be promising electrocatalysts for MOR and  
EGOR, the origin of the catalytic enhancement is still far away  
from complete understanding. 【本文，首次报道了螺旋状纳米线的合成方法，通过调控成分】

【本文，首次报道了螺旋状纳米线的合成方法，通过调控成分】

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Herein, we report for the rst  
time a developing strategy to synthesize screw-like PdPt NWs  
with tunable composition. 【本文，纳米线合成、电沉积、无模板和活性剂】

【本文，纳米线合成、电沉积、无模板和活性剂】

[4] J. X. Tang, Q. S. Chen, L. X. You, H. G. Liao, S. G. Sun, S. G. Zhou, Z. N. Xu, Y. M. Chen, G. C. Guo, Screw-like PdPt nanowires as highly efficient electrocatalysts for methanol and ethylene glycol oxidation, Journal of Materials Chemistry A, 2018, 6: 2327-2336.

The PdPt NWs were successfully  
prepared by a programmed potential electrodeposition method  
without using any templates and surfactants under room  
temperature conditions. 【本文，制备的纳米线，有高指数晶面，高的活性和稳定性】

【本文，制备的纳米线，有高指数晶面，高的活性和稳定性】

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The as-prepared PdPt NWs enclosed  
with high-index facets show excellent catalytic activity and  
enhanced durability for methanol and EG electrooxidation.  
【本文，利用。。。研究， 涉及。。反应的中间产物等被揭示】

【本文，利用。。。研究， 涉及。。反应的中间产物等被揭示】

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Using in situ FTIR spectroscopic investigations, the intermediates and products involved in the MOR and EGOR on PdPt NWs  
were revealed. 【】

## [5] C. Shang, Y. Guo, E. Wang, Facile fabrication of PdRuPt nanowire networks with tunable compositions as efficient methanol electrooxidation catalysts, Nano Research, 2018, 1-8.

1 Introduction  
【贵金属，应用于催化，生物，电子，等离子领域，由于吸引人的特性】

【贵金属，应用于催化，生物，电子，等离子领域，由于吸引人的特性】

[5] C. Shang, Y. Guo, E. Wang, Facile fabrication of PdRuPt nanowire networks with tunable compositions as efficient methanol electrooxidation catalysts, Nano Research, 2018, 1-8.

Noble metal nanomaterials are widely used in catalysis,  
biology, electronics, and plasmonics due to their fascinating  
properties [1–4]. 【pt等被用于燃料电池阳极催化剂，由于高的催化性能】

【pt等被用于燃料电池阳极催化剂，由于高的催化性能】

[5] C. Shang, Y. Guo, E. Wang, Facile fabrication of PdRuPt nanowire networks with tunable compositions as efficient methanol electrooxidation catalysts, Nano Research, 2018, 1-8.

In particular, Pt and Pd are the most  
popular noble metals used in anode catalysts for direct  
methanol fuel cells (DMFCs) because of their superior  
catalytic performances [5–7]. 【大量规则形状pt被制备】

【大量规则形状pt被制备】

[5] C. Shang, Y. Guo, E. Wang, Facile fabrication of PdRuPt nanowire networks with tunable compositions as efficient methanol electrooxidation catalysts, Nano Research, 2018, 1-8.

Many Pt and Pd nanocrystals  
with well-defined shapes have been successfully prepared  
in the past decades [8–11].【单金属在活性、稳定性方面，不能满足甲醇氧化催化】

【单金属在活性、稳定性方面，不能满足甲醇氧化催化】

[5] C. Shang, Y. Guo, E. Wang, Facile fabrication of PdRuPt nanowire networks with tunable compositions as efficient methanol electrooxidation catalysts, Nano Research, 2018, 1-8.

However, the catalytic activity  
and the durability of nanocrystals composed only of  
Pt or Pd are still not sufficient for catalyzing methanol  
oxidation in DMFCs. In order to achieve the required  
performances, large amounts of noble metals have to be employed in the cells, making the DMFCs too expensive for commercial production. 【通过减少使用量提高活性】

【通过减少使用量提高活性】

[5] C. Shang, Y. Guo, E. Wang, Facile fabrication of PdRuPt nanowire networks with tunable compositions as efficient methanol electrooxidation catalysts, Nano Research, 2018, 1-8.

In order to reduce the cost  
of DMFCs, the catalytic properties of the catalyst must  
be improved, which would allow reducing the usage  
of noble metals. 【活性对形状、尺寸、成分等敏感】

【活性对形状、尺寸、成分等敏感】

[5] C. Shang, Y. Guo, E. Wang, Facile fabrication of PdRuPt nanowire networks with tunable compositions as efficient methanol electrooxidation catalysts, Nano Research, 2018, 1-8.

It has been demonstrated that the  
catalytic properties of nanocrystals are sensitive to

their shape, size, and composition [12–14]. 【大多数研究关注于合金化、形貌可控制备】

【大多数研究关注于合金化、形貌可控制备】

[5] C. Shang, Y. Guo, E. Wang, Facile fabrication of PdRuPt nanowire networks with tunable compositions as efficient methanol electrooxidation catalysts, Nano Research, 2018, 1-8.

Therefore,  
most studies aimed to optimize the nanocrystal properties  
focus on alloying Pt or Pd with cheaper metals, while  
at the same time tuning the morphology of the final  
nanomaterials [10, 15–17].  
 【提高性能，采用双功能机制，通过合金化策略】

【提高性能，采用双功能机制，通过合金化策略】

[5] C. Shang, Y. Guo, E. Wang, Facile fabrication of PdRuPt nanowire networks with tunable compositions as efficient methanol electrooxidation catalysts, Nano Research, 2018, 1-8.

A popular and effective strategy to improve the  
catalytic performances of Pt nanomaterials involves  
taking advantage of bifunctional mechanisms, by alloying  
Ru with Pt [18–20]. 【Pt容易被CO毒化】

【Pt容易被CO毒化】

[5] C. Shang, Y. Guo, E. Wang, Facile fabrication of PdRuPt nanowire networks with tunable compositions as efficient methanol electrooxidation catalysts, Nano Research, 2018, 1-8.

When used as methanol oxidation  
electrocatalysts, Pt nanocrystals tend to be easily poisoned  
by CO intermediates, with a consequent degradation  
of catalytic activity [21, 22]. 【】Ru leads to water dissociation,  
producing OH species that could facilitate the removal  
of poisoning intermediates and, as a result, enhance  
the catalytic performances of Pt [23]. Moreover, alloying  
Pd with Pt is another effective way to produce promising  
nanocatalysts, which has attracted enormous attention  
[24–28]. 【各种形状的的Pt催化剂迄今被制备，具有高性能】

【各种形状的的Pt催化剂迄今被制备，具有高性能】

[5] C. Shang, Y. Guo, E. Wang, Facile fabrication of PdRuPt nanowire networks with tunable compositions as efficient methanol electrooxidation catalysts, Nano Research, 2018, 1-8.

Various PtPd bimetallic nanocatalysts have  
been prepared to date, and some of them possess superior  
catalytic properties for alcohol electrooxidation [5, 16,  
29–31].【】 Therefore, the simultaneous introduction of  
Ru and Pd into Pt nanocrystals is expected to produce  
promising methanol electrooxidation catalysts. 【除了成分影响外，调控形貌提高性能】

【除了成分影响外，调控形貌提高性能】

[5] C. Shang, Y. Guo, E. Wang, Facile fabrication of PdRuPt nanowire networks with tunable compositions as efficient methanol electrooxidation catalysts, Nano Research, 2018, 1-8.

Apart  
from varying the elemental composition, manipulating  
the morphology is another useful approach to improve  
the performance of the catalyst.【纳米线受到关注、由于促进电子传导、抗腐蚀】

【纳米线受到关注、由于促进电子传导、抗腐蚀】

[5] C. Shang, Y. Guo, E. Wang, Facile fabrication of PdRuPt nanowire networks with tunable compositions as efficient methanol electrooxidation catalysts, Nano Research, 2018, 1-8.

Among various reported  
nanostructures, one-dimensional nanomaterials have  
attracted particular interests, due to their ability to  
promote electron transfer and their resistance to corrosion  
[32, 33]. The above analysis thus highlights the potential  
importance of investigating the synthesis of nanocrystals  
with effective Pd, Ru, and Pt components and favorable  
one-dimensional nanostructures.  
 【复杂成本纳米结构通过模板制备，工艺复杂】

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[5] C. Shang, Y. Guo, E. Wang, Facile fabrication of PdRuPt nanowire networks with tunable compositions as efficient methanol electrooxidation catalysts, Nano Research, 2018, 1-8.

However, many reported nanomaterials with complex  
compositions have been prepared through template  
methods requiring complicated procedures. 【多成分化学合成仍具有挑战行，由于前驱体还原电位不同】

【多成分化学合成仍具有挑战行，由于前驱体还原电位不同】

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The direct  
synthesis of multicomponent nanomaterials with favorable  
structures through wet chemical methods is still a major  
challenge, because the reduction potentials of the  
precursors are significantly different from each other.【】  
In particular, the reduction of Ru elements usually needs  
high reaction temperatures and prolonged reaction time  
[34, 35]. Therefore, developing methods for synthesizing  
the desired nanomaterials under environmentally friendly  
conditions will be highly beneficial.  
【本文，报道了具有纳米线网络，三元纳米材料的制备】

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[5] C. Shang, Y. Guo, E. Wang, Facile fabrication of PdRuPt nanowire networks with tunable compositions as efficient methanol electrooxidation catalysts, Nano Research, 2018, 1-8.

In this work, we describe the direct synthesis of  
trimetallic PdRuPt nanomaterials with nanowire network  
morphology. 【本文，制备过程涉及前驱体还原】

【本文，制备过程涉及前驱体还原】

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The preparation process involved the  
reduction of relevant precursors with NaBH4. 【本文，。。指导了一维纳米线的形成】

【本文，。。指导了一维纳米线的形成】

[5] C. Shang, Y. Guo, E. Wang, Facile fabrication of PdRuPt nanowire networks with tunable compositions as efficient methanol electrooxidation catalysts, Nano Research, 2018, 1-8.

KBr  
proved essential to direct the formation of special  
one-dimensional nanostructures. 【本文，。。。作为表面剂】

【本文，。。。作为表面剂】

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Polyvinylpyrrolidone  
(PVP) was also added to the reaction solution and  
served as surfactant agent.【本文，最终产物成分可以通过相关前驱体的量控制】

【本文，最终产物成分可以通过相关前驱体的量控制】

[5] C. Shang, Y. Guo, E. Wang, Facile fabrication of PdRuPt nanowire networks with tunable compositions as efficient methanol electrooxidation catalysts, Nano Research, 2018, 1-8.

The composition of the  
final products could be easily tuned by varying the  
added amount of relevant precursors. 【本文，催化性能被评估，。。。显示了高活性和稳定性，相比于。。。】

【本文，催化性能被评估，。。。显示了高活性和稳定性，相比于。。。】

[5] C. Shang, Y. Guo, E. Wang, Facile fabrication of PdRuPt nanowire networks with tunable compositions as efficient methanol electrooxidation catalysts, Nano Research, 2018, 1-8.

The catalytic  
activities for methanol electrooxidation in an acidic  
medium were then evaluated, and the prepared PdRuPt  
nanocrystals exhibited higher catalytic activity and  
stability compared to PtPd nanomaterials with a similar  
structure and commercial Pt/C【】

## [6] E. Mazzotta, A. Caroli, A. Pennetta, G. E. De Benedetto, E. Primiceri, A. G. Monteduro, G. Maruccio, C. Malitesta, Facile synthesis of 3D flower-like Pt nanostructures on polypyrrole nanowire matrix for enhanced methanol oxidation, RSC Advances, 2018, 8: 10367-10375.

Introduction  
【Pt具有很好的催化性能，引起广泛研究，被应用于化学传感、产氢、汽车尾气还原、燃料电池】

【Pt具有很好的催化性能，引起广泛研究，被应用于化学传感、产氢、汽车尾气还原、燃料电池】

[6] E. Mazzotta, A. Caroli, A. Pennetta, G. E. De Benedetto, E. Primiceri, A. G. Monteduro, G. Maruccio, C. Malitesta, Facile synthesis of 3D flower-like Pt nanostructures on polypyrrole nanowire matrix for enhanced methanol oxidation, RSC Advances, 2018, 8: 10367-10375.

Platinum electrocatalytic properties are well-known since long  
and have stimulated extensive research leading to several  
applications, mainly related to its use in chemical sensors1 and  
as catalyst in the production of hydrogen from methane,2 in the  
reduction of pollutant gases emitted from automobiles3 and in  
fuel cells. 4 【催化效率、选择性依赖于尺寸、形状】

【催化效率、选择性依赖于尺寸、形状】

[6] E. Mazzotta, A. Caroli, A. Pennetta, G. E. De Benedetto, E. Primiceri, A. G. Monteduro, G. Maruccio, C. Malitesta, Facile synthesis of 3D flower-like Pt nanostructures on polypyrrole nanowire matrix for enhanced methanol oxidation, RSC Advances, 2018, 8: 10367-10375.

It is generally accepted that both catalytic efficiency  
and selectivity are highly dependent on the size and shape of  
platinum material.【大量尺寸、形状可控的工作被做】

【大量尺寸、形状可控的工作被做】

[6] E. Mazzotta, A. Caroli, A. Pennetta, G. E. De Benedetto, E. Primiceri, A. G. Monteduro, G. Maruccio, C. Malitesta, Facile synthesis of 3D flower-like Pt nanostructures on polypyrrole nanowire matrix for enhanced methanol oxidation, RSC Advances, 2018, 8: 10367-10375.

In the past several years many achievements  
have been made in the synthesis of Pt nanocatalysts, including  
size-controlled5 and shape-controlled Pt nanostructures. 【由于Pt高成本，使得人们提高pt效率，因此Pt纳米材料合成受到越来越多关注】

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6 Such  
a growing interest towards the synthesis of nanosized Pt has  
been encouraged also by the need of promoting a highly effi-  
cient platinum use due to its expensive nature critically limiting  
its technological viability.  
【策略之一是通过调控形貌获得更多活性点位，如、边角、台阶】

【策略之一是通过调控形貌获得更多活性点位，如、边角、台阶】

[6] E. Mazzotta, A. Caroli, A. Pennetta, G. E. De Benedetto, E. Primiceri, A. G. Monteduro, G. Maruccio, C. Malitesta, Facile synthesis of 3D flower-like Pt nanostructures on polypyrrole nanowire matrix for enhanced methanol oxidation, RSC Advances, 2018, 8: 10367-10375.

At the present, one of the explored strategies toward this  
direction consists in tailoring the shape and morphology of Pt based nanostructures, especially approaching to more catalytically active sites (corners, edges, steps, etc. ) or more active facets.7 【这就是为何，花状结构作为具有竞争力的材料出现，由于三维结构，提供面积和活性位点，为反应分子提供吸附点】

【这就是为何，花状结构作为具有竞争力的材料出现，由于三维结构，提供面积和活性位点，为反应分子提供吸附点】

[6] E. Mazzotta, A. Caroli, A. Pennetta, G. E. De Benedetto, E. Primiceri, A. G. Monteduro, G. Maruccio, C. Malitesta, Facile synthesis of 3D flower-like Pt nanostructures on polypyrrole nanowire matrix for enhanced methanol oxidation, RSC Advances, 2018, 8: 10367-10375.

This is why, among various developed Pt  
nanoarchitectures, including nanoparticles,8 nanosheets,9  
cauliower-like10 and cubic11 particles, very recently nano-  
owers have emerged as compelling materials due to their  
three-dimension structure, which provides favorable surface  
areas and active centers for electrocatalysis supplying enough  
adsorption sites for all involved molecules in a narrow space. 【三维花状提供了机会去提高活性】

【三维花状提供了机会去提高活性】

[6] E. Mazzotta, A. Caroli, A. Pennetta, G. E. De Benedetto, E. Primiceri, A. G. Monteduro, G. Maruccio, C. Malitesta, Facile synthesis of 3D flower-like Pt nanostructures on polypyrrole nanowire matrix for enhanced methanol oxidation, RSC Advances, 2018, 8: 10367-10375.

Indeed, the synthesis of 3D Pt nanoowers (PtNF) offers a valid  
chance to enhance the catalytic performance of Pt nanomaterials, 【】as shown by the high research interest devoted to this  
eld during the last years, leading to several successful catalytic  
applications of PtNF, especially in fuel cells fabrication.  
Although in some cases the synthesis of PtNF has been  
successfully achieved directly on bare at substrates such as  
glassy carbon,10,12–16 ITO electrodes16–20 and silicon substrates,18  
an important role has been increasingly recognized to the Pt  
catalyst supports, used for the dispersion of catalyst particles  
with the aim to increase the interfacial surface area, and thus to  
enhance the electrocatalytic performances. Carbon based  
materials as carbon nanotubes (CNTs),21 graphene sheets,22  
carbon paper23 revealed to be suitable candidate for such  
applications due to their unique properties as high surface area,  
electrical conductivity and high mechanical strength. Nonetheless, in most cases, their assembly results in carbon nano-  
lms embedding the catalyst, having a few nanometer, not  
easily tunable thickness, and thus limiting the overall 3D spatial

organization. In the case of CNTs, limitations in obtaining a 3D  
open structure are related also to their insolubility and strong  
tendency to aggregate in aqueous solutions.21 The development  
of novel catalyst supports for obtaining highly dispersed PtNF  
on a three-dimension highly open structure can thus represent  
a strategy for further enhancing Pt catalytic efficiency and  
constitute one of the major challenges in research today. Such  
requirement is particularly stringent in methanol oxidation  
based fuel cells where the removal of gaseous products could be  
also promoted by the use of anodes with open 3D internal  
structure.5  
The assembly of nanocomposites integrating PtNF and 3D  
support materials has been recently proposed. Zhang et al. 24  
fabricated a graphene 3D foam by using a nickel foam as  
template and subsequently depositing Pt ower-like nanoparticles by galvanic replacement reaction between Ni and Pt.  
The observed enhanced catalytic behavior is induced, according  
to authors, by the highly dispersed Pt nanoparticles with more  
exposed active sites, indicating the high utilization of Pt. With  
the aim of improving CNT functionalization with PtNF,  
obtaining a controllable deposition on easily dispersible CNT in  
solution, Yang et al. 21 adopted the polymer wrapping technique  
using poly(sodium 4-styrenesulfonate) (PSS) as modifying  
polymer. In the proposed mechanism, PSS plays a dual role:  
dispersing stable CNTs into solution in water, and providing  
functional groups that bind Pt nanoparticles. As-prepared  
composite systems showed a large electroactive specic  
surface area, and presented excellent electrocatalytic activity for  
oxygen reduction due to highly dispersed catalyst on the CNT  
support. A 3D structure integrating PtNF has been developed by  
Wang et al. 25 who proposed the synthesis of PtNF on porous  
silicon by a two-step approach consisting in a physical modi-  
cation of silicon surface to obtain a rough surface with high  
surface energy, achieved by inductively coupled plasma etching,  
and a chemical modication to create S–H groups acting as  
reducing agent, realized by HF pretreatment, involved in PtNF  
deposition onto porous silicon through chemical reduction.  
The high surface area structure thus obtained was responsible  
for the excellent electrocatalytic activity for methanol oxidation  
reaction.  
In the panorama of support material for Pt catalyst, also the  
use of conducting polymers, especially with nanosized structure26,27 has been successfully proposed as an effective strategy  
for enhancing metal electrocatalytic activity due to the high  
catalyst dispersion promoted by polymer nanostructure, and to  
possible synergistic effect involving both catalyst and support  
polymer.28 Nonetheless, to the best of our knowledge,  
approaches described so far are restricted to Pt nanoparticles,  
with the only example on PtNF integrated with polyaniline  
nanober focused on not catalytic sensing applications.29  
In the present work, for the rst time, the synthesis of Pt  
ower-like nanostructures is performed on a conducting polymeric support consisting of a three-dimension polypyrrole  
nanowires (PPyNWs) matrix, obtaining a composite material  
with excellent catalytic performances, tested against methanol  
oxidation. The improved electrocatalytic behavior is ascribed to  
the combined effect of high surface area ower-like structures  
and polymer nanowire 3D structure possibly promoting their  
high dispersion while keeping small charge transfer resistance  
and fast reaction rate due to good PPy electron conductivity.26  
The developed PtNF/PPyNW system is assembled by a facile  
electrochemical approach without using any seed, template or  
surfactant, allowing the simple and rapid deposition of PPy  
nanowires and, subsequently, PtNF directly on the electrode  
surface with good adherence and high homogeneity. The use of  
a whole electrochemical approach results to be benecial  
respect to chemical synthesis routes21,25 requiring organic  
ligand stabilizers which can be difficult to separate and can  
have a negative impact on the performance of the catalysts, and  
using multi-step, time consuming and complex procedures  
limiting applicability and large-scale production. In addition,  
the use of an electrochemically synthesized nanostructured  
conducting polymer as support material, contrarily to other  
developed 3D structure integrating PtNFs,24,25 offers the additional benets of properly tuning its morphology by controlling  
some experimental parameters,27 also in relation to the desired  
(catalytic) applications, by using a low-cost, commercially  
available technology

## [7] M. Luo, Y. Sun, X. Zhang, Y. Qin, M. Li, Y. Li, C. Li, Y. Yang, L. Wang, P. Gao, G. Lu, S. Guo, Stable High-Index Faceted Pt Skin on Zigzag-Like PtFe Nanowires Enhances Oxygen Reduction Catalysis, Advanced Materials, 2018, 30.

Proton exchange membrane fuel cells  
(PEMFCs) are widely considered as the  
ideal alternative to conventional internal  
combustion engine in areas of transportation, and stationary and portable power  
generation owing to their potential to solve  
the global problems of energy supply and  
environmental concern.[1–4] 【缓慢动力学阻碍燃料电池发展】

【缓慢动力学阻碍燃料电池发展】

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However, the  
wide deployment of PEMFCs is hindered  
by the sluggish kinetics of oxygen reduction reaction (ORR) at cathode even when  
the best metal catalyst (Pt) is used.[5–9]  
【发展高活性、低成本催化剂至关重要】

【发展高活性、低成本催化剂至关重要】

[7] M. Luo, Y. Sun, X. Zhang, Y. Qin, M. Li, Y. Li, C. Li, Y. Yang, L. Wang, P. Gao, G. Lu, S. Guo, Stable High-Index Faceted Pt Skin on Zigzag-Like PtFe Nanowires Enhances Oxygen Reduction Catalysis, Advanced Materials, 2018, 30.

To overcome this obstacle, it is crucial to  
develop inexpensive catalysts with much  
higher ORR activities.[10,11]  
【】An attractive strategy to boost ORR  
activity on Pt-based catalysts is to introduce a second transition metal (M) and to  
judiciously tailor the near-surface composition and structure, taking advantage of  
favorable ligand and strain effects to boost  
ORR activity.[12–15] For example, previous  
studies have identifid a nanosegregated  
Pt-skin structure to be extremely active

for ORR. By exposing Pt-skin Pt3Ni with three typical low-index  
facets (111), (100), and (110), the (111) faceted Pt-skin Pt3Ni  
delivers much higher ORR activity than the (100) and (110)  
faceted one, and nearly two orders of magnitude higher ORR  
specifi activity than the state-of-the-art carbon supported  
Pt nanoparticles (Pt/C).[16] To date, much research has been  
devoted to transferring the unique (111) faceted Pt3M skin  
onto practical nanocatalysts, leading to the development of  
promising Pt-based nanocatalysts shaped in octahedron,[17–21]  
icosahedron,[22] and nanoframe.[23–25] These studies not only  
demonstrate the importance of inducing nanosegregated  
Pt-skin structure but also suggest the strong dependence of  
ORR electrocatalysis on the exposed Pt facets.[26] Since the  
intrinsic ORR activity on Pt single-crystal thin fim follows  
the ranking: high-index facets (HIFs)  (111)  (100),[6,27,28] one  
would expect that by creating HIF Pt skin on the surface of  
Pt  
3M nanocrystal would lead to enhanced ORR activity. However, higher surface energies of the HIFs render such structures  
unlikely to be achieved, especially during thermal annealing  
process necessary for the formation of the Pt-skin structure.[29]  
Another critical concern is that even if such desirable structure  
could be formed, maintaining it under the operational condition of fuel cells poses a great challenge.  
Taking these challenges head on, we are able to produce an  
extremely stable HIF Pt skin onto 1D Pt3Fe zigzag-like nanowires (NWs), delivering much more active and durable ORR  
catalysis. The Pt-skin Pt3Fe zigzag-like NWs (denoted as Pt-skin  
Pt  
3Fe z-NWs) were prepared by fist simultaneously reducing  
the Pt and Fe precursors to yield Pt3Fe z-NWs, and subsequently  
thermally annealing the z-NWs at high temperature (see the  
Supporting Information for details). Compared to typical nanoparticulate morphologies, the 1D z-NWs are highly unusual  
with a HIF Pt skin, stemming from their anisotropic nature.  
This unique 1D catalyst enables an unprecedented ORR mass  
activity of 2.11 A mg−1 and a specifi activity of 4.34 mA cm−2,  
which are the highest among all the reported PtFe-based catalysts, at 0.9 V versus reversible hydrogen electrode (RHE), far  
exceeding those of commercial Pt/C catalyst and the technique  
target set by the U.S. DOE. Density function theory (DFT) calculations reveal that the strong ligand and strain effect resulted  
from a combination of exposed HIFs and Pt-skin structure  
leads to optimal oxygen adsorption energy, giving rise to much  
enhanced ORR activity. Surprisingly, the HIFs enclosed Pt-skin  
Pt  
3Fe z-NWs are also electrochemically stable under electrocatalytic conditions, with little activity decay and negligible structure  
transformation after a long-term course of 50 000 potential  
cycles. Meanwhile, the Pt-skin Pt3Fe z-NWs/C also shows signifiantly improved catalytic performance toward the anodic  
methanol/ethanol oxidation reaction (MOR/EOR) over the pristine Pt  
3Fe z-NWs/C and commercial Pt/C counterparts.  
A facile wet-chemical approach was used to synthesize Pt3Fe  
z-NWs by using platinum (II) acetylacetonate (Pt(acac)2) and  
iron(III) acetylacetonate (Fe(acac) 3) as the metal precursors,  
glucose as the reducing agent, cetyltrimethylammonium chloride (CTAC) as the surfactant, and oleylamine as the solvent.  
Control experiments were carried out to identify the optimal  
synthetic parameters for the Pt3Fe z-NWs by tuning the feeding  
ratios of metal precursors, the amount of glucose and CTAC.  
We found that a proper amount of reducing agent (glucose)

and surfactant (CTAC), which controls the kinetics of nucleation and growth of nanocrystals,[30,31] is the key to the formation  
of 1D nanostructures (Figures S1 and S2, Supporting Information). In addition, the feeding ratio of Pt to Fe precursors has  
little influence on the fial composition of Pt3Fe z-NWs, but  
largely impacts the Zigzag-like structure of NWs (Figures S3  
and S4, Supporting Information).  
【本文，形貌被tem,stem表征】

【本文，形貌被tem,stem表征】

[7] M. Luo, Y. Sun, X. Zhang, Y. Qin, M. Li, Y. Li, C. Li, Y. Yang, L. Wang, P. Gao, G. Lu, S. Guo, Stable High-Index Faceted Pt Skin on Zigzag-Like PtFe Nanowires Enhances Oxygen Reduction Catalysis, Advanced Materials, 2018, 30.

The morphology of as-synthesized Pt3Fe z-NWs was characterized by transmission electron microscopy (TEM) and  
high-angle annular dark-fild scanning transmission electron  
microscopy (HAADF-STEM). 【】As shown in Figure 1a,b, 1D  
z-NWs enclosed by highly uneven surfaces were the dominant  
product. They have the lengths of hundreds of nanometers and  
diameters of around 10 nm, leading to an average aspect ratio  
of 40. The composition of Pt to Fe in z-NWs was determined  
to be 76.2/23.8 by the STEM energy-dispersive X-ray spectroscopy (STEM-EDS) (Figure 1c), in accordance with the result  
from inductively coupled plasma-atomic emission spectroscopy  
(ICP-AES). The Pt3Fe z-NWs have a face-centered cubic (fcc)  
structure, as revealed by the powder X-ray diffraction (PXRD)  
pattern (Figure 1d). The main diffraction peaks of Pt3Fe z-NWs  
are located between those of fcc Pt (JCPDS No. 04-0802) and fcc  
Fe (JCPDS No. 52-0513), suggesting the formation of alloys.[32]  
The STEM-EDS mapping of single Pt3Fe z-NW reveals the  
homogeneous distribution of Pt and Fe throughout the NW  
without notable composition segregation (Figure 1e), indicating  
typical solid solution phase of Pt3Fe z-NWs. We further used  
aberration-corrected STEM to characterize the atomic structure of Pt  
3Fe z-NWs along the zone axis of [110], and found the  
uneven surface of z-NWs was dominated by HIFs, such as (311)  
and (211) facets, that were previously reported to be highly desirable for electrocatalysis (Figure S5, Supporting Information).[33]

## [8] Q. Lu, L. Sun, X. Zhao, J. Huang, C. Han, X. Yang, One-pot synthesis of interconnected Pt95Co5 nanowires with enhanced electrocatalytic performance for methanol oxidation reaction, Nano Research, 2018, 11: 2562-2572.

1 Introduction  
With growing global demand for clean and sustainable  
energy sources, proton exchange membrane fuel cells  
(PEMFCs) have received much research attention due  
to their high energy density, low pollutant emission,  
and facile operating temperature [1–3]. Direct methanol  
fuel cells (DMFCs)—which directly convert the chemical  
energy of methanol to electricity—are considered  
potential power suppliers for automobiles and portable  
electronics [4, 5]. 【发展高活性催化剂是实现商业化的途径】

【发展高活性催化剂是实现商业化的途径】

[8] Q. Lu, L. Sun, X. Zhao, J. Huang, C. Han, X. Yang, One-pot synthesis of interconnected Pt95Co5 nanowires with enhanced electrocatalytic performance for methanol oxidation reaction, Nano Research, 2018, 11: 2562-2572.

Developing highly active electrocatalysts for the methanol oxidation reaction (MOR)  
is an ideal way to realize the commercialization of  
this technology [6, 7]. 【Pt易毒化，降低活性、稳定性】

【Pt易毒化，降低活性、稳定性】

[8] Q. Lu, L. Sun, X. Zhao, J. Huang, C. Han, X. Yang, One-pot synthesis of interconnected Pt95Co5 nanowires with enhanced electrocatalytic performance for methanol oxidation reaction, Nano Research, 2018, 11: 2562-2572.

To date, platinum is the most  
effective monometallic catalyst in DMFCs but the Pt  
surface is prone to poisoning by strongly adsorbed  
intermediate species, hindering MOR activity and  
long-term stability [8–10]. 【pt资源少，成本高】

【pt资源少，成本高】

[8] Q. Lu, L. Sun, X. Zhao, J. Huang, C. Han, X. Yang, One-pot synthesis of interconnected Pt95Co5 nanowires with enhanced electrocatalytic performance for methanol oxidation reaction, Nano Research, 2018, 11: 2562-2572.

The low natural abundance

and high price of Pt also severely limit its utilization  
[11]. 【期望发展高活性、低使用量催化剂，提高性能】

【期望发展高活性、低使用量催化剂，提高性能】

[8] Q. Lu, L. Sun, X. Zhao, J. Huang, C. Han, X. Yang, One-pot synthesis of interconnected Pt95Co5 nanowires with enhanced electrocatalytic performance for methanol oxidation reaction, Nano Research, 2018, 11: 2562-2572.

Thus, it is desirable to design Pt-based bimetallic  
electrocatalysts to simultaneously minimize Pt consumption and improve electrochemical performance  
[12–14].【】  
Following this research interest, Pt-based nanocrystals  
(NCs) including PtAu [15], PtRu [16], PtPd [17], PtCu  
[18], PtCo [19], and others [20] were studied. The  
most cost-effective choice is to combine Pt with a  
cheap 3d-transition metal such as Fe, Co, Ni, or Cu  
[21–24]. It has been reported that the introduction of  
3d-transition metals in Pt-based NCs can weaken the  
adsorption of oxygenated species and increase the  
number of active sites [25–27]. 【提高利用率途径，控制形状，文献】

【提高利用率途径，控制形状，文献】

[8] Q. Lu, L. Sun, X. Zhao, J. Huang, C. Han, X. Yang, One-pot synthesis of interconnected Pt95Co5 nanowires with enhanced electrocatalytic performance for methanol oxidation reaction, Nano Research, 2018, 11: 2562-2572.

Another way to increase  
Pt utilization is by controlling the shape of Pt-based  
NCs [28]. Zhang et al. demonstrated the synthesis of  
PtCu nanoframes with higher activity toward MOR  
than previously reported PtCu tetragonal superstructures and dendritic PtCu nanoparticles [29, 30].  
【！！！近来实验表明，相比普通颗粒，一维结构，纳米线，纳米管，纳米棒，不易溶解，团聚，Ostwald熟化】

【！！！近来实验表明，相比普通颗粒，一维结构，纳米线，纳米管，纳米棒，不易溶解，团聚，Ostwald熟化】

[8] Q. Lu, L. Sun, X. Zhao, J. Huang, C. Han, X. Yang, One-pot synthesis of interconnected Pt95Co5 nanowires with enhanced electrocatalytic performance for methanol oxidation reaction, Nano Research, 2018, 11: 2562-2572.

Recent experiments indicated that one-dimensional  
(1D) Pt-based nanostructures such as nanowires  
(NWs), nanorods (NRs), and nanotubes (NTs) are less  
vulnerable to dissolution, aggregation, and Ostwald  
ripening than conventional nanoparticles [9]. 【纳米线自身的无支持特性导致没有碳基底腐蚀】

【纳米线自身的无支持特性导致没有碳基底腐蚀】

[8] Q. Lu, L. Sun, X. Zhao, J. Huang, C. Han, X. Yang, One-pot synthesis of interconnected Pt95Co5 nanowires with enhanced electrocatalytic performance for methanol oxidation reaction, Nano Research, 2018, 11: 2562-2572.

They  
can also eliminate the corrosion of carbon supports  
due to their inherent self-supporting feature [31, 32].  
 【纳米线合成方法】

【纳米线合成方法】

[8] Q. Lu, L. Sun, X. Zhao, J. Huang, C. Han, X. Yang, One-pot synthesis of interconnected Pt95Co5 nanowires with enhanced electrocatalytic performance for methanol oxidation reaction, Nano Research, 2018, 11: 2562-2572.

The reported synthetic approaches for 1D nanostructures mainly include template-directed synthesis  
[33], direct decomposition of organometallic precursors  
[34], modified phase-transfer [35], and surfactant mediated self-assembly [36]. Typically, PtRu NTs and  
PtRu/Cu NWs prepared by the galvanic replacement  
of Cu NWs show enhanced specific activities toward  
MOR relative to PtRu/C [37]. Chen et al. synthesized  
trimetallic PtPdCu NWs with tunable composition  
with the assistance of surfactant Triton X-114 [38]. 【尽管成功，工艺复杂，覆盖剂去除困难、不利于大规模化】

【尽管成功，工艺复杂，覆盖剂去除困难、不利于大规模化】

[8] Q. Lu, L. Sun, X. Zhao, J. Huang, C. Han, X. Yang, One-pot synthesis of interconnected Pt95Co5 nanowires with enhanced electrocatalytic performance for methanol oxidation reaction, Nano Research, 2018, 11: 2562-2572.

Despite these successful demonstrations, the reported  
routes usually involved complicated multistep procedures and difficult conditions for removing capping  
agents, which are disadvantageous for large-scale  
synthesis [33, 36–38]. 【迫切需要一步，无表面剂制备方法】

【迫切需要一步，无表面剂制备方法】

[8] Q. Lu, L. Sun, X. Zhao, J. Huang, C. Han, X. Yang, One-pot synthesis of interconnected Pt95Co5 nanowires with enhanced electrocatalytic performance for methanol oxidation reaction, Nano Research, 2018, 11: 2562-2572.

Development of a one-pot and  
surfactant-free route for the synthesis of Pt-based  
NWs in high yield is hence demanding.  
【为克服以上问题，发展一步法制备纳米线】

【为克服以上问题，发展一步法制备纳米线】

[8] Q. Lu, L. Sun, X. Zhao, J. Huang, C. Han, X. Yang, One-pot synthesis of interconnected Pt95Co5 nanowires with enhanced electrocatalytic performance for methanol oxidation reaction, Nano Research, 2018, 11: 2562-2572.

To address the aforementioned issues, we present a  
one-pot solvothermal strategy for preparing bimetallic  
Pt95Co5 NWs. 【纳米线定向生长机理】

【纳米线定向生长机理】

[8] Q. Lu, L. Sun, X. Zhao, J. Huang, C. Han, X. Yang, One-pot synthesis of interconnected Pt95Co5 nanowires with enhanced electrocatalytic performance for methanol oxidation reaction, Nano Research, 2018, 11: 2562-2572.

The oriented attachment mechanism  
was proposed to better understand the formation  
process. 【一体化纳米线、清洁表面、提高活性和稳定性】

【一体化纳米线、清洁表面、提高活性和稳定性】

[8] Q. Lu, L. Sun, X. Zhao, J. Huang, C. Han, X. Yang, One-pot synthesis of interconnected Pt95Co5 nanowires with enhanced electrocatalytic performance for methanol oxidation reaction, Nano Research, 2018, 11: 2562-2572.

The integrated design of the 1D NW structure,  
bimetallic composition, and clean particle surfaces  
enhanced Pt95Co5 NWs activity and durability toward  
MOR relative to pure Pt NWs and commercial Pt/C  
catalyst. 【】Owing to the straightforward synthesis and  
superior electrocatalytic properties, as-prepared Pt95Co5  
NWs hold great potential for application in DMFCs

## [9] X. Jiang, G. Fu, X. Wu, Y. Liu, M. Zhang, D. Sun, L. Xu, Y. Tang, Ultrathin AgPt alloy nanowires as a high-performance electrocatalyst for formic acid oxidation, Nano Research, 2018, 11: 499-510.

**1 Introduction**  
With the progressive exhaustion of combustion-based  
fossil fuels, the exploration of renewable and sustainable  
energy sources is under high demand, and has long  
been a hot frontier subject in energy and materials  
areas. Direct formic acid (HCOOH) fuel cells (DFAFCs)  
are an appealing alternative energy conversion system  
owing to their distinct advantages, such as high power  
output, lower fuel crossover, convenient storage and  
portability, and environmental benignity [1–4]. The  
advancement and large-scale commercialization of

high-performance DFAFCs greatly relies on the anode  
electrocatalyst that catalyzes the formic acid oxidation  
reaction (FAOR). 【Pt广泛用于甲酸电池】

【Pt广泛用于甲酸电池】

[9] X. Jiang, G. Fu, X. Wu, Y. Liu, M. Zhang, D. Sun, L. Xu, Y. Tang, Ultrathin AgPt alloy nanowires as a high-performance electrocatalyst for formic acid oxidation, Nano Research, 2018, 11: 499-510.

Metallic Pt is the most commonly  
used electrocatalyst toward the FAOR [5, 6]. 【甲酸机制及pt失活】

【甲酸机制及pt失活】

[9] X. Jiang, G. Fu, X. Wu, Y. Liu, M. Zhang, D. Sun, L. Xu, Y. Tang, Ultrathin AgPt alloy nanowires as a high-performance electrocatalyst for formic acid oxidation, Nano Research, 2018, 11: 499-510.

It is welldocumented that the electrooxidation of formic acid  
on Pt catalysts usually proceeds via a dual-pathway  
mechanism, i.e., a dehydrogenation pathway producing  
CO2 and a dehydration pathway generating CO-like  
poisoning intermediates [7–11]. These intermediates  
may cause the fatal deactivation and poor stability of  
the Pt catalyst. 【Pt高成本、资源少挑战】

【Pt高成本、资源少挑战】

[9] X. Jiang, G. Fu, X. Wu, Y. Liu, M. Zhang, D. Sun, L. Xu, Y. Tang, Ultrathin AgPt alloy nanowires as a high-performance electrocatalyst for formic acid oxidation, Nano Research, 2018, 11: 499-510.

Furthermore, the scarce reserves and  
high cost of Pt also pose severe challenges for the  
widespread application of DFAFCs. 【发展高效的Pt催化剂】

【发展高效的Pt催化剂】

[9] X. Jiang, G. Fu, X. Wu, Y. Liu, M. Zhang, D. Sun, L. Xu, Y. Tang, Ultrathin AgPt alloy nanowires as a high-performance electrocatalyst for formic acid oxidation, Nano Research, 2018, 11: 499-510.

Therefore, it is  
highly urgent to develop efficient substitutes for pure  
Pt catalysts to both enhance their poisoning resistance  
and minimize the overall consumption of this precious  
metal [12–14]. 【】To address these issues, the alloying of  
Pt with another less expensive metal could not only  
reduce the overall usage of Pt, but also bring about an  
optimized electrocatalytic performance due to possible  
synergetic effects [15–19]. Among various metals, Ag  
has manifested as a particularly promising alloying  
candidate to improve the FAOR activity and antipoisoning capability of Pt electrocatalysts, thanks to its  
low cost, high conductivity, superior catalytic activity,  
and improved CO tolerance [20–25].  
 【合理的结构调控可提高催化活性】

【合理的结构调控可提高催化活性】

[9] X. Jiang, G. Fu, X. Wu, Y. Liu, M. Zhang, D. Sun, L. Xu, Y. Tang, Ultrathin AgPt alloy nanowires as a high-performance electrocatalyst for formic acid oxidation, Nano Research, 2018, 11: 499-510.

On the other hand, rational manipulation of the  
nanostructure also provides a powerful means to  
tune or improve the catalyst properties. 【由于独一无二的结构特性，纳米线广受关注、优势】

【由于独一无二的结构特性，纳米线广受关注、优势】

[9] X. Jiang, G. Fu, X. Wu, Y. Liu, M. Zhang, D. Sun, L. Xu, Y. Tang, Ultrathin AgPt alloy nanowires as a high-performance electrocatalyst for formic acid oxidation, Nano Research, 2018, 11: 499-510.

Structurally,  
one-dimensional (1D) ultrathin nanowires have aroused  
extensive research interest due to their unique structural  
characteristics [26–31]. 【相比于颗粒，纳米线不易溶解，团聚，熟化，提高了传输，高表面活性】

【相比于颗粒，纳米线不易溶解，团聚，熟化，提高了传输，高表面活性】

[9] X. Jiang, G. Fu, X. Wu, Y. Liu, M. Zhang, D. Sun, L. Xu, Y. Tang, Ultrathin AgPt alloy nanowires as a high-performance electrocatalyst for formic acid oxidation, Nano Research, 2018, 11: 499-510.

In comparison with their 0D  
counterparts, 1D ultrathin nanowires are less susceptible  
to dissolution, agglomeration, and Ostwald ripening  
during electrocatalysis, and hence exhibit a higher  
structural robustness. Furthermore, the 1D structural  
anisotropy could facilitate mass and electron transport,  
which are favorable for an enhanced electrocatalytic  
activity [32, 33]. Moreover, the ultrathin nanowires  
could expose a high percentage of surface atoms  
and offer abundant catalytically active sites, further  
reducing the usage of noble metals and increasing  
the atom-utilization efficiency [34]. 【一体化合金协同效应和结构优势具有重要意义】

【一体化合金协同效应和结构优势具有重要意义】

[9] X. Jiang, G. Fu, X. Wu, Y. Liu, M. Zhang, D. Sun, L. Xu, Y. Tang, Ultrathin AgPt alloy nanowires as a high-performance electrocatalyst for formic acid oxidation, Nano Research, 2018, 11: 499-510.

Taken together, the  
integration of the synergistic effects of the AgPt alloy  
and the structural advantages derived from using  
ultrathin nanowires are of great significance. 【】By  
addressing these unsolved issues, ultrathin AgPt alloy  
nanowires would be an ideal efficient electrocatalyst  
towards the FAOR.  
 【本文，呈现纳米线制备方法】

【本文，呈现纳米线制备方法】

[9] X. Jiang, G. Fu, X. Wu, Y. Liu, M. Zhang, D. Sun, L. Xu, Y. Tang, Ultrathin AgPt alloy nanowires as a high-performance electrocatalyst for formic acid oxidation, Nano Research, 2018, 11: 499-510.

Herein, we demonstrate a facile synthetic strategy  
for achieving ultrathin AgPt alloy nanowires with  
a high yield and uniformity. 【】We find that the use  
of amine-terminated poly(N-isopropylacrylamide)  
(PNIPAM-NH2, molecular structure displayed in Fig. S1  
in the Electronic Supplementary Material (ESM)) as  
a structure-directing agent and an appropriate Ag:Pt  
molar ratio are prerequisites for the formation of  
ultrathin AgPt alloy nanowires. The mechanistic study  
indicates that the formation of these nanowires involves  
the initial generation of AgCl precipitates, subsequent  
formation of AgPt nanoparticles, and their oriented  
attachment along the <111> direction. Due to the alloy  
composition and 1D structure, the ultrathin AgPt  
nanowires exhibit a superior electrocatalytic activity  
and better CO tolerance for the FAOR than AgPt  
nanoparticles and a commercial Pt black catalyst. This  
behavior suggests that such ultrathin AgPt nanowires  
may hold great promise in practical DFAFCs and  
beyond.  
2 Experimental

## [10] L. Huang, X. Zhang, Q. Wang, Y. Han, Y. Fang, S. Dong, Shape-Control of Pt-Ru Nanocrystals: Tuning Surface Structure for Enhanced Electrocatalytic Methanol Oxidation, Journal of the American Chemical Society, 2018, 140: 1142-1147.

■ INTRODUCTION

Fuel cells, such as proton exchange membrane fuel cells  
(PEMFCs) and direct methanol fuel cells (DMFCs), are  
promising renewable energy devices for converting chemical  
energy into electric power with no fossil fuels or environmental  
sensitivity.1 −5 As the methanol oxidation reaction (MOR) is a  
basic anode reaction of DMFCs, developing highly efficient  
electrocatalysts for MOR is the key to fabricating high-energy/  
power density fuel cells. 【Pt受到关注，由于高活性】

【Pt受到关注，由于高活性】

[10] L. Huang, X. Zhang, Q. Wang, Y. Han, Y. Fang, S. Dong, Shape-Control of Pt-Ru Nanocrystals: Tuning Surface Structure for Enhanced Electrocatalytic Methanol Oxidation, Journal of the American Chemical Society, 2018, 140: 1142-1147.

Platinum nanomaterials have received  
intensive research interest due to their superior catalytic nature  
in MOR.6 −10【大量努力致力于可控合成，提高活性，文献】

【大量努力致力于可控合成，提高活性，文献】

[10] L. Huang, X. Zhang, Q. Wang, Y. Han, Y. Fang, S. Dong, Shape-Control of Pt-Ru Nanocrystals: Tuning Surface Structure for Enhanced Electrocatalytic Methanol Oxidation, Journal of the American Chemical Society, 2018, 140: 1142-1147.

Increasing efforts are being devoted to promoting  
the catalytic activity by precisely controlled synthesis of Pt  
nanostructures with tailored shapes and compositions, 11 −17 for  
example, bimetallic Pt-M alloys (M = Pd, Ru, Fe, Co, Ni, Cu,  
Sn, and Pb) with various morphologies (nanopolyhedra,  
nanowires, nanosheets, and nanodendrites).18 −26 【CO的毒化是挑战】

【CO的毒化是挑战】

[10] L. Huang, X. Zhang, Q. Wang, Y. Han, Y. Fang, S. Dong, Shape-Control of Pt-Ru Nanocrystals: Tuning Surface Structure for Enhanced Electrocatalytic Methanol Oxidation, Journal of the American Chemical Society, 2018, 140: 1142-1147.

However,  
CO poisoning catalyst surfaces is still a challenge, where the  
CO originates from dissociation of methanol molecules during  
the electrocatalytic reaction.27 −29

【甲醇CO毒化途径】

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[10] L. Huang, X. Zhang, Q. Wang, Y. Han, Y. Fang, S. Dong, Shape-Control of Pt-Ru Nanocrystals: Tuning Surface Structure for Enhanced Electrocatalytic Methanol Oxidation, Journal of the American Chemical Society, 2018, 140: 1142-1147.

Both density functional  
theory and model experiments have revealed the possible CO  
poisoning route: the Pt atom site catalyzes oxidation of a  
methanol molecule to form strongly adsorbed COads, which can  
only be further oxidized to CO2 at large overpotentials. Hence,  
Pt-CO  
ads is considered a poisoning intermediate and hinders  
the further methanol oxidation on Pt catalyst surfaces.30 −34【Pt合金中引入Ru】

【Pt合金中引入Ru】

[10] L. Huang, X. Zhang, Q. Wang, Y. Han, Y. Fang, S. Dong, Shape-Control of Pt-Ru Nanocrystals: Tuning Surface Structure for Enhanced Electrocatalytic Methanol Oxidation, Journal of the American Chemical Society, 2018, 140: 1142-1147.

According to poison resistance research on Pt-based catalysts in  
MOR, PtRu bimetallic nanomaterials are recognized as the  
best-performing CO-poisoning-tolerant electrocatalysts to date,  
and this can be explained by the Watanabe −Motoo bifunctional  
mechanism. The addition of an oxophilic metal, Ru, to Pt can  
provide adsorbed hydroxyl groups (OHads) at lower potential  
than on pristine Pt, which serves as the oxidant to remove the  
poisoning species (COads) by oxidizing it to CO2.35 −39  
【期望得到形状可控的PtRu】

【期望得到形状可控的PtRu】

[10] L. Huang, X. Zhang, Q. Wang, Y. Han, Y. Fang, S. Dong, Shape-Control of Pt-Ru Nanocrystals: Tuning Surface Structure for Enhanced Electrocatalytic Methanol Oxidation, Journal of the American Chemical Society, 2018, 140: 1142-1147.

Meanwhile, various reported PtRu catalysts exhibit outstanding  
MOR electrocatalytic activity, but the high reduction potential  
and lattice mismatch of Ru make it a great challenge to  
synthesize shape-controlled PtRu nanocrystals rather than  
irregular nanoparticles.40 −47【系统研究形状与催化性能关联性具有重要意义】

【系统研究形状与催化性能关联性具有重要意义】

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In this regard, it is significant to  
systematically research the correlations of well-defined Pt −Ru  
nanocrystals with MOR catalytic properties.

【本文，这里报道了形貌可控合成，一步法，研究了活性】

【本文，这里报道了形貌可控合成，一步法，研究了活性】

[10] L. Huang, X. Zhang, Q. Wang, Y. Han, Y. Fang, S. Dong, Shape-Control of Pt-Ru Nanocrystals: Tuning Surface Structure for Enhanced Electrocatalytic Methanol Oxidation, Journal of the American Chemical Society, 2018, 140: 1142-1147.

Herein, we report the systematic synthesis of ultrathin PtRu  
nanocrystals with tunable morphologies (nanowires, nanorods,  
nanocubes, and nanoparticles) through a one-step wet-chemical  
approach and investigate their electrocatalytic activities in the  
oxidation of methanol. 【】The PtRu nanocrystals are typically  
synthesized by a one-pot hydrothermal method in oleylamine  
(OAm)-based systems, with Pt(acac)2 and Ru(acac)3 as the  
metal precursors, W(CO)6 as reducing agent, and additional  
surfactants as structure-directing agents. 【尤其值得注意的是，形状的形成的关键因素】

【尤其值得注意的是，形状的形成的关键因素】

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Notably, the morphologies of the nanocrystals are facilely controlled by different  
kinds/amount of surfactants (Scheme 1). For instance, an  
appropriate amount of DDAC can lead to ultrathin PtRu  
nanowires (PtRu NWs), CTAB can lead to PtRu nanocubes  
(PtRu NCs), and increasing amounts of HDBAC can shorten  
the length of PtRu nanorods (denoted as PtRu NRs1, PtRu  
NRs  
2, and PtRu NRs3, corresponding to lengths of 60, 45, and  
30 nm, respectively). 【本文，电化学性能描述，活性稳定性】

【本文，电化学性能描述，活性稳定性】

[10] L. Huang, X. Zhang, Q. Wang, Y. Han, Y. Fang, S. Dong, Shape-Control of Pt-Ru Nanocrystals: Tuning Surface Structure for Enhanced Electrocatalytic Methanol Oxidation, Journal of the American Chemical Society, 2018, 140: 1142-1147.

Furthermore, the as-obtained uniform  
PtRu nanocrystals exhibit excellent electrocatalytic activity and  
stability toward MOR. The PtRu NWs show the highest mass  
activity of 0.82 A mgPt −1 and specific activity of 1.16 mA cm −2,  
which are superior to the values for other shapes of PtRu  
catalysts and commercial Pt/C catalysts. 【】

## [11] W. Zhao, B. Ni, Q. Yuan, Y. Wang, Q. Zhang, X. Wang, Finely Composition-Tunable Synthesis of Ultrafine Wavy PtRu Nanowires as Effective Electrochemical Sensors for Dopamine Detection, Langmuir, 2017, 33: 8070-8075.

■ INTRODUCTION  
【纳米线受到关注，由于各向异性、电子传导，抗腐蚀等】

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Today, the synthesis of Pt-based one-dimensional (1D)  
nanowires has been paid great attention because their inherent  
anisotropic nature can result in many impressive performances.  
1 −6 In addition, 1D nanowires have many other merits  
such as improving electron-transport and mass-transport  
characteristics and being self-supporting electrocatalysts that  
avoids support corrosion.7 −9 【尺寸和成分影响活性】

【尺寸和成分影响活性】

[11] W. Zhao, B. Ni, Q. Yuan, Y. Wang, Q. Zhang, X. Wang, Finely Composition-Tunable Synthesis of Ultrafine Wavy PtRu Nanowires as Effective Electrochemical Sensors for Dopamine Detection, Langmuir, 2017, 33: 8070-8075.

Meanwhile, the size and  
composition also intrinsically determine the catalytic performance of catalysts because size reduction can help increase unit  
mass utilization of Pt,10 −12 and Pt alloying with other transition  
metals (Pd, Au, Ag, Ni, Cu, Zn, Co, Rh, and Ru) can help to  
dramatically improve the catalytic activity due to the synergic  
effect and electronic effect.13 −26 【缺陷和晶界影响催化性能】

【缺陷和晶界影响催化性能】

[11] W. Zhao, B. Ni, Q. Yuan, Y. Wang, Q. Zhang, X. Wang, Finely Composition-Tunable Synthesis of Ultrafine Wavy PtRu Nanowires as Effective Electrochemical Sensors for Dopamine Detection, Langmuir, 2017, 33: 8070-8075.

Moreover, pioneering  
researches have shown that the structural defects/grain  
boundaries have a crucial effect on the catalytic performance  
of metal nanostructures.27 −33 【有缺陷/晶界的纳米线合成具有重要意义】

【有缺陷/晶界的纳米线合成具有重要意义】

[11] W. Zhao, B. Ni, Q. Yuan, Y. Wang, Q. Zhang, X. Wang, Finely Composition-Tunable Synthesis of Ultrafine Wavy PtRu Nanowires as Effective Electrochemical Sensors for Dopamine Detection, Langmuir, 2017, 33: 8070-8075.

Therefore, rational design and  
synthesis of Pt-based ultrafine 1D alloy nanowires with  
abundant structural defects/grain boundaries are really  
desirable and of great importance in nanoscale science and  
technology.  
【PtRu的应用】

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[11] W. Zhao, B. Ni, Q. Yuan, Y. Wang, Q. Zhang, X. Wang, Finely Composition-Tunable Synthesis of Ultrafine Wavy PtRu Nanowires as Effective Electrochemical Sensors for Dopamine Detection, Langmuir, 2017, 33: 8070-8075.

Bimetallic PtRu alloy nanostructures are widely used as  
catalysts in hydrogenation reactions,34,35 fuel cells,36 −39 and  
electrochemical glucose biosensors.40,41 【据我们所知，很少有。。。。方面的报道】

【据我们所知，很少有。。。。方面的报道】

[11] W. Zhao, B. Ni, Q. Yuan, Y. Wang, Q. Zhang, X. Wang, Finely Composition-Tunable Synthesis of Ultrafine Wavy PtRu Nanowires as Effective Electrochemical Sensors for Dopamine Detection, Langmuir, 2017, 33: 8070-8075.

To the best of our knowledge, however, there is no report for PtRu nanostructures  
to be utilized in electrochemical biosensors for the detection of  
dopamine (DA) thus far. 【】DA (3,4-dihydroxyphenyl ethylamine) serves as a significant catecholamine neurotransmitter  
and was discovered to exist in the mammalian brain in the  
1950s.42 The concentration of DA is between 0.01 μM and 1  
μM in serum samples. A variety of diseases, such as epilepsy,  
Parkinsonism, schizophrenia, Alzheimer’s disease, and pleasurable feelings and euphoria,43 −45 will be induced when the  
concentration of DA is abnormal in biological fluids. Currently,  
the electrochemical method that would exhibit many  
conveniences and advantages to avoid the drawbacks of  
surface-enhanced Raman scattering,46 colorimetry,47 chemiluminescence.48 and conventional enzymatic sensors,49 is  
commonly used to recognize DA because DA can be easily  
oxidized by the catalyst-modified glassy carbon electrode  
(GCE).50 −52 However, the sensitivity, limit of detection  
(LOD), selectivity, and antipoisoning performance greatly  
impede commercial applications in electrochemical DA sensors.  
Therefore, the development of a new type of high-performance  
electrode catalyst material for electrochemical DA sensors is of

t r e m e n d o u s i m p o r t a n c e i n c l i nical diagnosis, biological  
medicine, and antidoping fields.  
【本文，引入。。。方法制备纳米线】

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[11] W. Zhao, B. Ni, Q. Yuan, Y. Wang, Q. Zhang, X. Wang, Finely Composition-Tunable Synthesis of Ultrafine Wavy PtRu Nanowires as Effective Electrochemical Sensors for Dopamine Detection, Langmuir, 2017, 33: 8070-8075.

In this paper, we introduce an environmentally friendly, facile  
aqueous solution approach to directly prepare high-yield, sub-  
3.0 nm PtRu ultrafine wavy nanowires with abundant structural  
defects/grain boundaries.【本文，纳米线。。。被可控，。。与性能关联性被研究】

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[11] W. Zhao, B. Ni, Q. Yuan, Y. Wang, Q. Zhang, X. Wang, Finely Composition-Tunable Synthesis of Ultrafine Wavy PtRu Nanowires as Effective Electrochemical Sensors for Dopamine Detection, Langmuir, 2017, 33: 8070-8075.

The composition of these PtRu  
ultrafine wavy nanowires can be finely tailored in a wide range  
from Pt  
10Ru0 to Pt4Ru6, which allows the correlation among  
composition and catalytic performance to be investigated. 【】This  
is the first report on the quantitative synthesis of ultrafine PtRu  
bimetallic nanowires according to feeding metal ratio of Pt to  
Ru in a relatively wide range. Furthermore, we also synthesized  
the pure Pt ultrafine wavy nanowires under the same  
conditions, and the size was similar to that of PtRu. We first  
introduced the as-synthesized PtRu ultrafine wavy nanowires  
into electrochemical biosensors for the detection of DA and  
found that the PtRu nanowires exhibited excellent electrocatalytic activity to DA with fast response, ultralow limit of  
detection (LOD), and excellent selectivity. 【纳米线性能依赖成分，高度敏感】

【纳米线性能依赖成分，高度敏感】

[11] W. Zhao, B. Ni, Q. Yuan, Y. Wang, Q. Zhang, X. Wang, Finely Composition-Tunable Synthesis of Ultrafine Wavy PtRu Nanowires as Effective Electrochemical Sensors for Dopamine Detection, Langmuir, 2017, 33: 8070-8075.

Meanwhile, the  
PtRu nanowires displayed a composition-dependent catalytic  
property toward DA oxidation and had a much higher  
sensitivity compared to pure Pt nanowires. 【】

## [12] N. Zhang, Y. Zhu, Q. Shao, X. Zhu, X. Huang, Ternary PtNi/PtxPb/Pt core/multishell nanowires as efficient and stable electrocatalysts for fuel cell reactions, Journal of Materials Chemistry A, 2017, 5: 18977-18983.

Introduction  
Fuel cells convert chemical energy into electrical energy through  
electrochemical reactions with the aid of electrocatalysts,1,2  
which can lower the reaction barrier to carry out the oxidation  
and reduction processes more efficiently. 【Pt是最高效催化剂】

【Pt是最高效催化剂】

[12] N. Zhang, Y. Zhu, Q. Shao, X. Zhu, X. Huang, Ternary PtNi/PtxPb/Pt core/multishell nanowires as efficient and stable electrocatalysts for fuel cell reactions, Journal of Materials Chemistry A, 2017, 5: 18977-18983.

Among various  
candidates, platinum (Pt) is regarded as the most effective  
catalyst component for both the anodic and cathodic fuel cell  
reactions.【Pt资源少，成本高】

【Pt资源少，成本高】

[12] N. Zhang, Y. Zhu, Q. Shao, X. Zhu, X. Huang, Ternary PtNi/PtxPb/Pt core/multishell nanowires as efficient and stable electrocatalysts for fuel cell reactions, Journal of Materials Chemistry A, 2017, 5: 18977-18983.

However, as one of the most rare and precious noble  
metals, the high cost of Pt largely restricts its practical applications.3–6 【为实现Pt高性能和利用率，需要设计特殊的结构】

【为实现Pt高性能和利用率，需要设计特殊的结构】

[12] N. Zhang, Y. Zhu, Q. Shao, X. Zhu, X. Huang, Ternary PtNi/PtxPb/Pt core/multishell nanowires as efficient and stable electrocatalysts for fuel cell reactions, Journal of Materials Chemistry A, 2017, 5: 18977-18983.

Therefore, it is a prerequisite to pursue Pt-based  
catalysts with unique nanostructures in order to realize both  
high performance and the maximized Pt utilization.  
【大量工作致力于尺寸、形状、成分提高利用率等】

【大量工作致力于尺寸、形状、成分提高利用率等】

[12] N. Zhang, Y. Zhu, Q. Shao, X. Zhu, X. Huang, Ternary PtNi/PtxPb/Pt core/multishell nanowires as efficient and stable electrocatalysts for fuel cell reactions, Journal of Materials Chemistry A, 2017, 5: 18977-18983.

Great efforts have been devoted to designing PtM (M ¼ nonnoble metal elements) nanostructures with a controlled size,  
shape and composition, owing to its potential for tuning the  
electronic structures and improving the intrinsic activity and Pt  
utilization.7–10 【】Generally, due to their potential in regulating the  
electronic structure as compared with bimetallic nanomaterials, ternary Pt-based nanomaterials are attracting  
increasing research interest.11 Unfortunately, it is difficult to  
prepare uniform ternary nanostructures because of the differences in reduction potentials and the lattice mismatch among  
different components.12,13 Furthermore, Pt-based catalysts with  
a core–shell structure were found to be promising to further  
enhance the catalytic activity for both anodic and cathodic  
reactions of fuel cells since their interface can tune both electronic and geometric effects, especially for the core/multishell  
structure.14–16 【除了活性，需要满足稳定性和耐腐蚀性的要求】

【除了活性，需要满足稳定性和耐腐蚀性的要求】

[12] N. Zhang, Y. Zhu, Q. Shao, X. Zhu, X. Huang, Ternary PtNi/PtxPb/Pt core/multishell nanowires as efficient and stable electrocatalysts for fuel cell reactions, Journal of Materials Chemistry A, 2017, 5: 18977-18983.

In addition to the demand for high catalytic  
activity, another restricting factor of the catalysts is durability  
owing to Ostwald ripening of the nanoparticles and the corrosion of carbon supports during the electrochemical  
processes.17–21 【纳米线优势，晶面，高稳定性，电子传输，受到关注】

【纳米线优势，晶面，高稳定性，电子传输，受到关注】

[12] N. Zhang, Y. Zhu, Q. Shao, X. Zhu, X. Huang, Ternary PtNi/PtxPb/Pt core/multishell nanowires as efficient and stable electrocatalysts for fuel cell reactions, Journal of Materials Chemistry A, 2017, 5: 18977-18983.

Due to their structural characteristics such as preferential exposure of reactive crystal facets, high durability,  
and facile electron transport, one dimensional (1D) nanostructures have attracted much attention in the past few years.22–30 【纳米线与基底作用提高性能】

【纳米线与基底作用提高性能】

[12] N. Zhang, Y. Zhu, Q. Shao, X. Zhu, X. Huang, Ternary PtNi/PtxPb/Pt core/multishell nanowires as efficient and stable electrocatalysts for fuel cell reactions, Journal of Materials Chemistry A, 2017, 5: 18977-18983.

Thanks to the nanowire (NW) structure, the interaction between the catalyst and the conductive support can be  
enhanced to facilitate electron transfer between the support  
and the NWs, thus promoting catalytic performance.31–34   
 【期望结合三元，核壳，纳米线一体化催化剂设计】

【期望结合三元，核壳，纳米线一体化催化剂设计】

[12] N. Zhang, Y. Zhu, Q. Shao, X. Zhu, X. Huang, Ternary PtNi/PtxPb/Pt core/multishell nanowires as efficient and stable electrocatalysts for fuel cell reactions, Journal of Materials Chemistry A, 2017, 5: 18977-18983.

Therefore, a rational design of advanced catalysts with the  
combined characteristics of a ternary, core–shell structure and  
1D structure for fuel cell reactions is highly desirable.  
 【本文，这里报道了。。策略】

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[12] N. Zhang, Y. Zhu, Q. Shao, X. Zhu, X. Huang, Ternary PtNi/PtxPb/Pt core/multishell nanowires as efficient and stable electrocatalysts for fuel cell reactions, Journal of Materials Chemistry A, 2017, 5: 18977-18983.

Herein, we report a facile strategy to prepare a new class of  
ternary PtNi/PtxPb/Pt core/multishell NWs with PtNi as the core  
and Pt  
xPb and Pt as shells for the rst time. 【本文，纳米线制备中。。。起到重要的作用】

【本文，纳米线制备中。。。起到重要的作用】

[12] N. Zhang, Y. Zhu, Q. Shao, X. Zhu, X. Huang, Ternary PtNi/PtxPb/Pt core/multishell nanowires as efficient and stable electrocatalysts for fuel cell reactions, Journal of Materials Chemistry A, 2017, 5: 18977-18983.

We found that the  
use of preformed ultrathin PtNi NWs as substrates, sequential  
reduction/diffusion of Pb onto the ultrathin PtNi NWs, and the  
further reduction of Pt play important roles in the formation of

ternary PtNi/PtxPb/Pt NWs. 【本文，电化学活性和稳定性】

【本文，电化学活性和稳定性】

[12] N. Zhang, Y. Zhu, Q. Shao, X. Zhu, X. Huang, Ternary PtNi/PtxPb/Pt core/multishell nanowires as efficient and stable electrocatalysts for fuel cell reactions, Journal of Materials Chemistry A, 2017, 5: 18977-18983.

They exhibit enhanced electrocatalytic activities towards various alcohol oxidations and the  
oxygen reduction reaction (ORR) compared with commercial  
Pt/C. Among all the catalysts, the optimized PtNi0.67Pb0.26 NWs  
exhibit the best activities for the methanol oxidation reaction  
(MOR) (2.4 A mgPt1, 3.1 mA cm 2), ethanol oxidation reaction  
(EOR) (0.83 A mgPt1, 1.07 mA cm 2), ethylene glycol oxidation  
reaction (EGOR) (0.42 A mgPt1, 0.65 mA cm 2), glycerol  
oxidation reaction (GOR) (0.36 A mgPt1, 0.61 mA cm 2) and  
ORR (1.08 A mgPt1, 1.39 mA cm 2), which are 9.2 and 6.7 times,  
3.8 and 3.5 times, 2.3 and 2.6 times, 3.3 and 4.1 times, and  
6.4 and 5.8 times higher than those of commercial Pt/C  
(0.26 A mgPt1 and 0.36 mA cm 2 for the MOR, 0.22 A mgPt1  
and 0.31 mA cm 2 for the EOR, 0.18 A mgPt1 and 0.25 mA cm 2  
for the EGOR, 0.11 A mgPt1 and 0.15 mA cm 2 for the GOR and  
0.17 A mgPt1 and 0.24 mA cm 2 for the ORR). The PtNi/PtxPb/Pt  
core/multishell NWs also exhibit enhanced durability, which  
position them as a promising electrocatalyst candidate for  
practical fuel cells.【】

## [13] N. Zhang, Y. Feng, X. Zhu, S. Guo, J. Guo, X. Huang, Superior Bifunctional Liquid Fuel Oxidation and Oxygen Reduction Electrocatalysis Enabled by PtNiPd Core–Shell Nanowires, Advanced Materials, 2017, 29.

【能源领域引出高效催化剂】

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Recently, a high demand of high-density energy is forcing researchers to develop highly effiient energy conversion  
devices, such as polymer electrolyte membrane fuel cells,  
which requires remarkably active and stable electrocatalysts  
for both the fuel oxidation reaction and oxygen reduction reaction (ORR).[1–3] 【Pt高效、但成本高】

【Pt高效、但成本高】

[13] N. Zhang, Y. Feng, X. Zhu, S. Guo, J. Guo, X. Huang, Superior Bifunctional Liquid Fuel Oxidation and Oxygen Reduction Electrocatalysis Enabled by PtNiPd Core–Shell Nanowires, Advanced Materials, 2017, 29.

Pt is proven as the most effiient catalyst; however, its high cost and slow kinetics largely limit its practical  
applications in fuel cell reactions.[4,5] 【期望设计最大利用率Pt 催化剂】

【期望设计最大利用率Pt 催化剂】

[13] N. Zhang, Y. Feng, X. Zhu, S. Guo, J. Guo, X. Huang, Superior Bifunctional Liquid Fuel Oxidation and Oxygen Reduction Electrocatalysis Enabled by PtNiPd Core–Shell Nanowires, Advanced Materials, 2017, 29.

To this end, it is highly  
desirable to develop effective strategies for designing high performance electrocatalysts with maximized Pt utilization.[6–9]  
 【核壳策略提高活性、降低成本，文献】

【核壳策略提高活性、降低成本，文献】

[13] N. Zhang, Y. Feng, X. Zhu, S. Guo, J. Guo, X. Huang, Superior Bifunctional Liquid Fuel Oxidation and Oxygen Reduction Electrocatalysis Enabled by PtNiPd Core–Shell Nanowires, Advanced Materials, 2017, 29.

One of the successful strategies to address such a challenge  
is constructing nanostructures with a Pt shell, in which both  
the exposure and the electronic effect of the surface Pt can be  
desirably increased.[10–13] Xia and co-workers have created core–  
shell structured Pd@Pt nanocrystals with enhanced ORR performance by depositing atomic layers of Pt on the well-defied  
Pd nanocrystals.[14] 【廉价金属替代策略提高活性、降低成本，文献】

【廉价金属替代策略提高活性、降低成本，文献】

[13] N. Zhang, Y. Feng, X. Zhu, S. Guo, J. Guo, X. Huang, Superior Bifunctional Liquid Fuel Oxidation and Oxygen Reduction Electrocatalysis Enabled by PtNiPd Core–Shell Nanowires, Advanced Materials, 2017, 29.

Another effective technique to enhance  
the performance of Pt-based electrocatalysts is to partially substitute Pt with a transition or less expensive metal, which can  
further regulate the electronic structure of Pt, then enhance its  
activity toward specifi applications.[15–21] For example, Stamenkovic et al. demonstrated that the single crystal (111) surface of  
Pt3Ni has promising ORR activity, which is 90-fold higher than  
commercial Pt/C.[22]【纳米线策略，大的界面，提高电荷传输，利于纳米线与基底结合，提高活性、降低成本】

【纳米线策略，大的界面，提高电荷传输，利于纳米线与基底结合，提高活性、降低成本】

[13] N. Zhang, Y. Feng, X. Zhu, S. Guo, J. Guo, X. Huang, Superior Bifunctional Liquid Fuel Oxidation and Oxygen Reduction Electrocatalysis Enabled by PtNiPd Core–Shell Nanowires, Advanced Materials, 2017, 29.

The third strategy to improve the catalytic  
performance concerns the creation of 1D Pt-based nanowires  
(NWs) because 1D nanostructures have larger interfacial area  
contacting with the support than nanoparticles (NPs). Such  
close contact enhances the electron transfer between reactants  
and the Pt surface, and also facilitates the binding between  
the NWs and the support, resulting in high activity and  
stability.[23–25] 【核壳，合金，纳米线结合，提高活性】

【核壳，合金，纳米线结合，提高活性】

[13] N. Zhang, Y. Feng, X. Zhu, S. Guo, J. Guo, X. Huang, Superior Bifunctional Liquid Fuel Oxidation and Oxygen Reduction Electrocatalysis Enabled by PtNiPd Core–Shell Nanowires, Advanced Materials, 2017, 29.

The integration of core–shell, alloy, and 1D structures into  
Pt-based nanomaterials thus seems natural and extremely benefiial for the creation of high-performance electrocatalysts with  
enhanced Pt utilization effiiency. 【本文，这里显示了。。制备。。。策略】

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[13] N. Zhang, Y. Feng, X. Zhu, S. Guo, J. Guo, X. Huang, Superior Bifunctional Liquid Fuel Oxidation and Oxygen Reduction Electrocatalysis Enabled by PtNiPd Core–Shell Nanowires, Advanced Materials, 2017, 29.

We demonstrate herein an  
ultrathin PtNi NW mediated strategy for creating a new class of  
core–shell trimetallic PtNiPd NWs for superior electrocatalysis.【】  
 The components of the PtNi shell were accurately controlled  
by varying the amount of the Ni precursor. 【本文，。。。是纳米线形成的关键因素】

【本文，。。。是纳米线形成的关键因素】

[13] N. Zhang, Y. Feng, X. Zhu, S. Guo, J. Guo, X. Huang, Superior Bifunctional Liquid Fuel Oxidation and Oxygen Reduction Electrocatalysis Enabled by PtNiPd Core–Shell Nanowires, Advanced Materials, 2017, 29.

The preformed  
ultrathin PtNi NWs and different reduction potentials of the  
precursors are the key factors for the successful creation of the  
trimetallic NWs with a core–shell structure. 【本文，纳米线显示了高活性】

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[13] N. Zhang, Y. Feng, X. Zhu, S. Guo, J. Guo, X. Huang, Superior Bifunctional Liquid Fuel Oxidation and Oxygen Reduction Electrocatalysis Enabled by PtNiPd Core–Shell Nanowires, Advanced Materials, 2017, 29.

As-prepared PtNiPd  
NWs exhibit enhanced performance for the ethylene glycoloxidation reaction (EGOR), glycerol oxidation reaction (GOR),  
and ORR with PtNi  
0.56Pd1.42 NWs showing the highest activities in each, superior to other PtNiPd NWs, PtNiPd NPs, and  
commercial Pt/C. 【本文，电化学稳定性】

【本文，电化学稳定性】

[13] N. Zhang, Y. Feng, X. Zhu, S. Guo, J. Guo, X. Huang, Superior Bifunctional Liquid Fuel Oxidation and Oxygen Reduction Electrocatalysis Enabled by PtNiPd Core–Shell Nanowires, Advanced Materials, 2017, 29.

The PtNiPd NWs are also stable in EGOR,  
GOR, and ORR with negligible activity decay after 2000 potential sweeping cycles for EGOR and GOR and 10 000 potential  
sweeping cycles for ORR in acidic condition. 【】

In a typical preparation of trimetallic PtNiPd core–shell  
NWs, platinum(II) acetylacetonate (Pt(acac)2), nickel(II) acetylacetonate (Ni(acac)2), and cetyltrimethylammonium chloride,  
glucose, and oleylamine were added into a glass vial and subjected to ultrasonication for 1 h. The fial mixture was then  
heated from room temperature to 160 C and maintained at  
160 C for 0.5 h under magnetic stirring. After cooling to 80 C  
(*t* ≈1 h), palladium(II) acetylacetonate (Pd(acac)2) in oleylamine  
was added dropwise to the above mixture. The reaction was  
then increased to 160 C and kept at 160 C for another 4 h. The  
colloidal products were collected by centrifugation. According  
to the low-magnifiation high-angle annular dark-fild scanning transmission electron microscopy (HAADF-STEM) image  
(Figure 1a), the NWs with a length up to a micrometer and high  
morphological uniformity were obtained. The average diameter of the NWs was 7 nm and the NWs are rough with many  
bumps on their surface, as shown in both TEM and HAADFSTEM images (Figure 1b,c). The molar ratio of Pt/Ni/Pd is  
1/1.21/1.36, as determined by the scanning electron microscopy  
energy-dispersive X-ray spectroscopy (SEM-EDS) (Figure S1a,b,  
Supporting Information). Powder X-ray diffraction (PXRD)  
was employed to characterize the trimetallic NWs shown in  
Figure S1c (Supporting Information). Compared with that of  
pure Pt, the diffractions of the NWs were shifted to higher 2   
angles owing to the decreased lattice constant of the Ni.[26,27] In  
addition, the main peaks can be split into two peaks, and the  
shoulder peaks reveal the existence of a PtNi shell (Figure S1d,  
Supporting Information). EDS elemental mappings (Figure 1d)  
were conducted to investigate the elemental distribution of the

NWs. It is apparent that Pd mainly distributes in the interior of  
the NWs, while both Pt and Ni distribute evenly along the whole  
NW, indicating the core–shell structure of the obtained NWs.  
HAADF-STEM images in the inset and the line-profie analysis  
using STEM-EDS confim that Pd is concentrated in the core  
region with a PtNi-rich surface (Figure 1e). The high resolution  
TEM (HRTEM) image (Figure 1f) shows that the obtained NWs  
are highly crystalline with clear interplanar spacing of 0.214 nm.  
Furthermore, the steps and kinks were frequently observed on  
the surface of PtNiPd NWs, as marked in Figure 1f, which will  
be benefiial for the enhanced catalysis.[28–30]

## [14] X. Yan, Y. Chen, S. Deng, Y. Yang, Z. Huang, C. Ge, L. Xu, D. Sun, G. Fu, Y. Tang, In Situ Integration of Ultrathin PtCu Nanowires with Reduced Graphene Oxide Nanosheets for Efficient Electrocatalytic Oxygen Reduction, Chemistry - A European Journal, 2017, 23: 16871-16876.

Introduction  
【燃料电池收到关注】

【燃料电池收到关注】

[14] X. Yan, Y. Chen, S. Deng, Y. Yang, Z. Huang, C. Ge, L. Xu, D. Sun, G. Fu, Y. Tang, In Situ Integration of Ultrathin PtCu Nanowires with Reduced Graphene Oxide Nanosheets for Efficient Electrocatalytic Oxygen Reduction, Chemistry - A European Journal, 2017, 23: 16871-16876.

Proton exchange membrane fuel cells (PEMFCs) have aroused  
numerous interests as promising current energy conversion devices for transportation and portable electronic equipment on account of the high energy conversion efficiency and environmental benignity. 【燃料电池动力学缓慢，引出Pt】

【燃料电池动力学缓慢，引出Pt】

[14] X. Yan, Y. Chen, S. Deng, Y. Yang, Z. Huang, C. Ge, L. Xu, D. Sun, G. Fu, Y. Tang, In Situ Integration of Ultrathin PtCu Nanowires with Reduced Graphene Oxide Nanosheets for Efficient Electrocatalytic Oxygen Reduction, Chemistry - A European Journal, 2017, 23: 16871-16876.

However, the overall efficiency of PEMFCs is greatly retarded by the sluggish reaction kinetics of the oxygen reduction reaction (ORR) because of the high overpotential and multiple electron transfer processes.[1] 【pt高效，资源少】

【pt高效，资源少】

[14] X. Yan, Y. Chen, S. Deng, Y. Yang, Z. Huang, C. Ge, L. Xu, D. Sun, G. Fu, Y. Tang, In Situ Integration of Ultrathin PtCu Nanowires with Reduced Graphene Oxide Nanosheets for Efficient Electrocatalytic Oxygen Reduction, Chemistry - A European Journal, 2017, 23: 16871-16876.

Currently, platinum (Pt) is considered as the most popular catalyst  
toward the ORR. Unfortunately, the extremely high cost and restricted resources of Pt greatly impede the practical application  
and scalable commercialization of PEMFCs.[2] 【期望低成本、高效Pt催化剂】

【期望低成本、高效Pt催化剂】

[14] X. Yan, Y. Chen, S. Deng, Y. Yang, Z. Huang, C. Ge, L. Xu, D. Sun, G. Fu, Y. Tang, In Situ Integration of Ultrathin PtCu Nanowires with Reduced Graphene Oxide Nanosheets for Efficient Electrocatalytic Oxygen Reduction, Chemistry - A European Journal, 2017, 23: 16871-16876.

Therefore, it is  
highly urgent to develop inexpensive alternative electrocatalysts without compromising the high ORR performance. 【】As a  
powerful strategy, introducing a secondary inexpensive metal  
to form Pt@M (M =Cu, Fe, Co, Ni, etc.) alloys could not only  
reduce the cost of the electrocatalysts, but also effectively  
modify the d-band center of Pt, which often gives rise to superior electrocatalytic properties, such as enhanced activity and  
sufficient stability.[1d,3] Particularly, Cu has been identified as a  
promising candidate to form Pt@Cu alloys with excellent catalytic performances owing to its relatively cheap price and the  
possible synergistic effect between Pt and Cu.[4] As such, PtCu  
bimetallic nanoalloys are considered to be a highly economical  
and efficient ORR electrocatalyst. 【性能依赖形貌】

【性能依赖形貌】

[14] X. Yan, Y. Chen, S. Deng, Y. Yang, Z. Huang, C. Ge, L. Xu, D. Sun, G. Fu, Y. Tang, In Situ Integration of Ultrathin PtCu Nanowires with Reduced Graphene Oxide Nanosheets for Efficient Electrocatalytic Oxygen Reduction, Chemistry - A European Journal, 2017, 23: 16871-16876.

On the other hand, the electrocatalytic performance also highly depends on the morphology of electrocatalysts. 【纳米线收到关注：优势，高长径比，表面原子，高性能、不易团聚、各向异性，加速电子传输】

【纳米线收到关注：优势，高长径比，表面原子，高性能、不易团聚、各向异性，加速电子传输】

[14] X. Yan, Y. Chen, S. Deng, Y. Yang, Z. Huang, C. Ge, L. Xu, D. Sun, G. Fu, Y. Tang, In Situ Integration of Ultrathin PtCu Nanowires with Reduced Graphene Oxide Nanosheets for Efficient Electrocatalytic Oxygen Reduction, Chemistry - A European Journal, 2017, 23: 16871-16876.

Particularly, ultrathin one-dimensional  
(1D) nanocatalysts have aroused extensive research interest because of the fantastic structural traits, such as high aspect ratio  
and high percentage of surface atoms, endowing them with  
superior electrocatalytic performance.[5] Moreover, compared  
with the 0D counterparts, ultrathin 1D nanostructures are less  
vulnerable to agglomeration, Ostwald ripening and dissolution,  
thus exerting an improved structural robustness.[6] Additionally,  
1D structural anisotropy could accelerate the electron transport, which is beneficial to enhance the electrocatalytic activity.[7] 【期望发展高效纳米线】

【期望发展高效纳米线】

[14] X. Yan, Y. Chen, S. Deng, Y. Yang, Z. Huang, C. Ge, L. Xu, D. Sun, G. Fu, Y. Tang, In Situ Integration of Ultrathin PtCu Nanowires with Reduced Graphene Oxide Nanosheets for Efficient Electrocatalytic Oxygen Reduction, Chemistry - A European Journal, 2017, 23: 16871-16876.

Therefore, it is highly desirable to develop effective alloyed Pt@Cu catalysts with ultrafine 1D structures to facilitate  
the ORR for PEMFCs.  
 【负载基体对催化具有重要作用】

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In addition to the above-mentioned composition and morphology of the Pt-based catalysts, the catalyst support also  
plays a vital role in improving the electrocatalytic activity and  
stability. 【氧化石墨烯优势】

【氧化石墨烯优势】

[14] X. Yan, Y. Chen, S. Deng, Y. Yang, Z. Huang, C. Ge, L. Xu, D. Sun, G. Fu, Y. Tang, In Situ Integration of Ultrathin PtCu Nanowires with Reduced Graphene Oxide Nanosheets for Efficient Electrocatalytic Oxygen Reduction, Chemistry - A European Journal, 2017, 23: 16871-16876.

Among the various available substrates, graphene

oxide (GO) represents a popular and versatile support for  
nanocatalyst loading because of its good electric conductivity,  
high surface area, and excellent tolerance under severe working conditions.[5c, 8] Considering the advantages of the 1D structure and the synergistic effect between metal nanowires and  
GO, metal nanowires/GO nanohybrids have been extensively  
studied.[7b, 9] 【以前的制备方法成本高，降低产率和纯度】

【以前的制备方法成本高，降低产率和纯度】

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In spite of these accomplished progresses, the previous synthetic protocols usually involved multiple and complicated synthetic procedures, which may increase the synthetic cost and decrease the overall product yield and purity.[10] 【】 Moreover, it is difficult to integrate multiple components with distinct physicochemical properties into one nano-entity owing to the incompatibility between different compositions. 【综合考虑，。。。仍存在挑战】

【综合考虑，。。。仍存在挑战】

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Taken together, it remains challenging to develop a simple and versatile strategy to fabricate GO-supported Pt-based nanowires for electrochemical energy applications. 【本文，这里报道了…合成方法】

【本文，这里报道了…合成方法】

[14] X. Yan, Y. Chen, S. Deng, Y. Yang, Z. Huang, C. Ge, L. Xu, D. Sun, G. Fu, Y. Tang, In Situ Integration of Ultrathin PtCu Nanowires with Reduced Graphene Oxide Nanosheets for Efficient Electrocatalytic Oxygen Reduction, Chemistry - A European Journal, 2017, 23: 16871-16876.

Herein, we report an in situ synthesis of ultrathin PtCu nanowires grown on reduced graphene oxide (PtCu-NWs/rGO) for  
the first time by a one-pot hydrothermal approach with the  
elaborate adoption of amine-terminated poly(N-isopropyl acrylamide) (PNIPAM-NH 2) as a structure-directing agent. 【本文，…对合成纳米线等起到。。的作用】

【本文，…对合成纳米线等起到。。的作用】

[14] X. Yan, Y. Chen, S. Deng, Y. Yang, Z. Huang, C. Ge, L. Xu, D. Sun, G. Fu, Y. Tang, In Situ Integration of Ultrathin PtCu Nanowires with Reduced Graphene Oxide Nanosheets for Efficient Electrocatalytic Oxygen Reduction, Chemistry - A European Journal, 2017, 23: 16871-16876.

The hydrophobic backbone of PNIPAM-NH 2 could interplay with the hydrophobic GO, facilitating the in situ deposition of metal nuclei  
on the surface of rGO through the interaction between metal  
precursors and the amino group and carbonyl group in  
PNIPAM-NH  
2.【本文，。。。可以诱导1维纳米线生长】

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[14] X. Yan, Y. Chen, S. Deng, Y. Yang, Z. Huang, C. Ge, L. Xu, D. Sun, G. Fu, Y. Tang, In Situ Integration of Ultrathin PtCu Nanowires with Reduced Graphene Oxide Nanosheets for Efficient Electrocatalytic Oxygen Reduction, Chemistry - A European Journal, 2017, 23: 16871-16876.

Furthermore, the presence of PNIPAM-NH 2 could  
also induce the 1D anisotropic growth of PtCu ultrathin nanowires. 【本文，电化学活性和稳定性】

【本文，电化学活性和稳定性】

[14] X. Yan, Y. Chen, S. Deng, Y. Yang, Z. Huang, C. Ge, L. Xu, D. Sun, G. Fu, Y. Tang, In Situ Integration of Ultrathin PtCu Nanowires with Reduced Graphene Oxide Nanosheets for Efficient Electrocatalytic Oxygen Reduction, Chemistry - A European Journal, 2017, 23: 16871-16876.

Owing to the structural and compositional advantages,  
the as-prepared PtCu-NWs/rGO exhibits much improved activity and better stability toward ORR compared with the rGOsupported PtCu nanoparticles (PtCu-NPs/rGO), PtCu nanowires  
(PtCu-NWs), and commercial Pt/C, making it a promising cathodic electrocatalyst for both fuel cells and metal–air cells. 【】

## [15] P. Wang, X. Zhang, J. Zhang, S. Wan, S. Guo, G. Lu, J. Yao, X. Huang, Precise tuning in platinum-nickel/nickel sulfide interface nanowires for synergistic hydrogen evolution catalysis, Nature Communications, 2017, 8.

【氢的挑战在于如何有效产氢】

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H ydrogen (H has been considered as a promising alternative to replace the diminishing fossil fuel2), as a clean and renewable energy resource,1–4. The grand challenge leading to extensive use of hydrogen energy system is to  
produce H2 in an efficient and cost-effective manner.  
 【由于…的优势，电化学水解制氢受到关注】

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[15] P. Wang, X. Zhang, J. Zhang, S. Wan, S. Guo, G. Lu, J. Yao, X. Huang, Precise tuning in platinum-nickel/nickel sulfide interface nanowires for synergistic hydrogen evolution catalysis, Nature Communications, 2017, 8.

Electrochemical water splitting by combining hydrogen  
evolution reaction (HER) and oxygen evolution reaction is  
attracting much attention due to its inherent advantages  
including accessible reactants, stable output, feasibility of largescale production and highly pure product5–10. 【】In general, HER is  
believed to consist of two pathways: Volmer/Tafel pathway or  
Volmer/Heyrovsky pathway11–13. However, the Heyrovsky and  
the Volmer steps have different expressions in acidic or basic  
media11–13. The reacting species are H2O/OH in the base  
solution and H þ in the acid solution; thus, the cleavage of HO–H  
bond in H2O is crucial for alkaline HER13,14. 【Pt是高效催化剂】

【Pt是高效催化剂】

[15] P. Wang, X. Zhang, J. Zhang, S. Wan, S. Guo, G. Lu, J. Yao, X. Huang, Precise tuning in platinum-nickel/nickel sulfide interface nanowires for synergistic hydrogen evolution catalysis, Nature Communications, 2017, 8.

To date, platinum  
(Pt) is generally considered as one of the best catalysts towards  
HER, particularly in acid media15–18. 【】 However, the HER kinetics  
of Pt is much slower in the alkaline condition, resulting in the  
HER activity that is approximately two to three orders of  
magnitude lower than in the acidic media19,20. This may be  
attributed to the fact that although Pt is conducive to the  
adsorption of reactive hydrogen intermediates (Hads) and their  
combination into H2 molecules, it is unfortunately not efficient in  
splitting water into Hads in the alkaline solution13,21,22. The slow  
kinetics in the alkaline solution leads to low efficiencies in both  
water-alkali and chlor-alkali electrolysers. Therefore, introducing  
‘promoters’ with the function to cleave HO–H bonds could  
open new opportunities to further enhance alkaline HER  
electrocatalysis13,14,23. However, which ‘promoter’ can work  
well with Pt to yield more efficient and durable HER catalysts  
remains an open question.  
Owing to intrinsic difference in the chemical reactivity of the  
metallic components, bimetallic nanocrystals with high composition  
segregation are exploited to develop unusual nanostructures with  
desirable functionalities24–30. They can create interior vacancies or  
open skeletons such as nanocages and nanoframes by readily  
sacrificing the relatively active metals27–30. 【本文，这里报道了。。。纳米线制备】

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[15] P. Wang, X. Zhang, J. Zhang, S. Wan, S. Guo, G. Lu, J. Yao, X. Huang, Precise tuning in platinum-nickel/nickel sulfide interface nanowires for synergistic hydrogen evolution catalysis, Nature Communications, 2017, 8.

Herein, we take the  
advantage of the highly composition-segregated Pt-Ni nanowires  
(NWs), to create a class of Pt3Ni/NiS heterostructures via a simple  
yet efficient sulfuration process. 【本文，。。纳米线显示了电化学活性】

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The Pt3Ni/NiS heterostructures  
with a high density of interfaces between NiS and Pt3Ni display  
excellent HER activity in both acidic and alkaline conditions.  
Specially, the optimized Pt3Ni2 NWs-S/C yield the highest activity  
in the alkaline condition with a current density of 37.2 mAcm2 at  
an overpotential of 70 mV, which is 9.7 times higher than that of  
the commercial Pt/C, representing the best electrocatalysts towards  
alkaline HER, to the best of our knowledge. 【本文，密度泛函理论揭示了。。】

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The density functional  
theory (DFT) calculations reveal that the synergy between NiS and  
Pt3Ni components can substantially enhance the HER activity in  
the alkaline solution with NiS promoting water dissociation,  
whereas Pt3Ni efficiently convert H þ to H2. 【本文，电化学稳定性】

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[15] P. Wang, X. Zhang, J. Zhang, S. Wan, S. Guo, G. Lu, J. Yao, X. Huang, Precise tuning in platinum-nickel/nickel sulfide interface nanowires for synergistic hydrogen evolution catalysis, Nature Communications, 2017, 8.

Moreover, these  
heterostructures also exhibit enhanced HER stability with limited  
activity decay after a long-term chronopotentiometry run.【】 The  
unprecedented catalytic performance offered by the novel Pt3Ni/  
NiS heterostructures highlights the importance of interfacial  
engineering in multicomponent electrocatalysts.

## [16] R. Sun, Z. Xia, L. Shang, X. Fu, H. Li, S. Wang, G. Sun, Hierarchically ordered arrays with platinum coated PANI nanowires for highly efficient fuel cell electrodes, Journal of Materials Chemistry A, 2017, 5: 15260-15265.

Introduction  
【由于…燃料电池受到关注】

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Polymer electrolyte membrane fuel cells (PEMFCs), as a class of  
the most promising alternative sources of energy technologies,  
have drawn much attention because of their high power density,  
quick start-up and low pollutant emission. 1– 3 【Pt匮乏仍是商业化的挑战】

【Pt匮乏仍是商业化的挑战】

[16] R. Sun, Z. Xia, L. Shang, X. Fu, H. Li, S. Wang, G. Sun, Hierarchically ordered arrays with platinum coated PANI nanowires for highly efficient fuel cell electrodes, Journal of Materials Chemistry A, 2017, 5: 15260-15265.

However, the  
massive use of the scarce platinum group metals (PGMs) is still  
one of the major challenges for the large scale commercialization of PEMFCs. 4– 7 【尽管大量工作致力于氧化物替代研发，Pt仍是高效活性】

【尽管大量工作致力于氧化物替代研发，Pt仍是高效活性】

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Despite the great efforts that have been made  
to substitute PGMs with materials based on metal oxide,  
nitrogen doped carbon, alloys, etc. , Pt and its alloys are still  
recognized as the most feasible materials to catalyse the oxygen  
reduction reaction (ORR) in the acidic environment of PEMFC  
cathodes. 8– 14 【提高Pt活性和利用率是燃料电池发展主要任务】

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Hence, a combination of optimization of the  
electrochemical activity and utilization of Pt has become one of  
the major tasks in the development of PEMFCs technologies.  
 【】On one hand, core–shell structures and nanoframe structures  
have been intensively studied due to their advantages in terms  
of extending the surface area through their delicate nanostructure. 1 These studies are usually synergetic with the alloy  
effects to adjust the electron structure to achieve an optimized  
ORR activity. On the other hand, the catalyst layer with welldened nanostructures that lead to effective electrochemical  
processes, namely the ordered electrode, is another route to  
achieve high utilization and activity of Pt. 15  
The ordered structured electrode, proposed by Middleman  
in 2002, in which electron, proton, reactant and product  
transport pathways were perpendicular to the membrane, was  
designed for maximizing the catalyst utilization and decreasing  
the mass transfer resistance of PEMFCs. 16 A signicant method  
to construct the above electrode structures was proposed by 3M  
Co., and the as-prepared electrode was denoted as a nanostructured thin film (NSTF) catalyst. 5,17,18 Such ordered arrays  
were composed of organic crystal substrates and columnar PGM  
arrays growing along the substrates. This orderliness at the  
multi-scale could be regarded as an effective approach to  
enhance catalyst utilization and mass transport compared to  
those of traditional electrodes with randomly arranged catalyst  
particles and mass transport channels based on carbon materials. Nevertheless, the insulation of both electrons and ions of  
the organic substrates in an NSTF catalyst and their rigorous  
synthesis and transfer processes could be the potential drawbacks for their further application. Additionally, other substrate  
materials used for this ordered electrode have rarely been  
reported.  
【大量研究利用导电基体形成纳米催化剂，规则传输通道】

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[16] R. Sun, Z. Xia, L. Shang, X. Fu, H. Li, S. Wang, G. Sun, Hierarchically ordered arrays with platinum coated PANI nanowires for highly efficient fuel cell electrodes, Journal of Materials Chemistry A, 2017, 5: 15260-15265.

Recently, many researchers have employed conductive  
supports to form advanced electrode structures, such as carbon  
nanotubes (CNTs), carbon nanofibers (CNFs) or metal dioxides. 8,19– 21 In our previous studies, conductive polymers, such as  
polypyrrole (PPy) and polyaniline (PANI), were developed as

membrane electrode assemblies (MEAs) in ordered nanostructures. 22– 24 With facile preparation procedures, excellent  
physical and electrochemical properties were achieved for the  
construction of ordered mass transport pathways at the mesoscale. However, based on these substrates, the active sites with  
well-defined electrochemical surfaces have still been seldom  
studied to the best of our knowledge, which should be recognized as the core factor attributed to the performance of electrochemical devices.  
 【本文，这里报道了多孔分级结构子传质生长在纳米线上】

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In this study, we, for the rst time, propose a hierarchically  
ordered electrode with crystallographically oriented Pt nanowhisker arrays anchored on vertically aligned PANI nanowires.  
【本文，通过优化参数，结构参数被调控满足反应和传输要求】

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By optimizing the fabrication conditions of chemical polymerization and magnetron sputtering, the structural parameters of  
this ordered electrode are controlled to meet the requirements  
of electrochemical reactions and mass transport at the microand meso-scales. 【本文，电化学性能被测】

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Its performance in electrochemically catalysing the ORR and as the PEMFC cathode for the ordered electrode is also measured. 【】

## [17] P. Song, X. Cui, Q. Shao, Y. Feng, X. Zhu, X. Huang, Networked Pt-Sn nanowires as efficient catalysts for alcohol electrooxidation, Journal of Materials Chemistry A, 2017, 5: 24626-24630.

Introduction  
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Recently, direct alcohol fuel cells (DAFCs), especially direct  
methanol/ethanol fuel cells (DMFCs or DEFCs), have attracted  
great research attention owing to their broad application prospects in human society and potential value in solving the crises of energy shortage and environmental pollution.1–6 【甲醇、乙醇催化机理，电子转移】

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The methanol oxidation reaction (MOR) is a six electron transfer process  
in DMFCs, while the ethanol oxidation reaction (EOR) involves  
a twelve electron transfer process upon complete oxidation and  
C–C bond splitting in DEFCs.7,8 Compared to the MOR, it is  
highly difficult to achieve C–C bond splitting through the  
complete oxidation of C2H5OH into CO2, to directly lead to the  
generation of the C2H5OH oxidation complex.9–11 【甲醇乙醇氧化动力学缓慢，需要高性能Pt催化剂】

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Moreover,  
both the MOR and EOR have also been hindered by sluggish  
kinetics at the anode, which greatly requires the design of high performance anode catalysts for alcohol electrooxidation.12–14  
 【Pt催化剂是甲醇乙醇的阳极催化剂】

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In general, anode catalysts for the MOR and EOR are usually  
Pt-based catalysts because of their high activity and efficiency.  
 【pt高成本、资源匮乏、易毒化】

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[17] P. Song, X. Cui, Q. Shao, Y. Feng, X. Zhu, X. Huang, Networked Pt-Sn nanowires as efficient catalysts for alcohol electrooxidation, Journal of Materials Chemistry A, 2017, 5: 24626-24630.

Given the scarcity, high cost and low poisoning tolerance of Pt,  
the practical applications of DAFCs are still limited to some  
extent.15–17 【】In view of the above facts, Pt-based bimetallic anode  
catalysts have been developed in recent research, such as Pt–Ru,  
Pt–Sn and Pt–Pd, which can effectively minimize the usage of Pt  
and enhance the catalytic activity by modifying the Pt electronic  
structure.7,18–21 Specically, oxophilic metals ( i.e., Rh, Sn and Ni)  
can promote the formation of adsorbed OH species through the  
dissociative adsorption of water, which contributes to the  
removal of adsorbed intermediates (COads and CHX,ads)  
conversely on the adjacent Pt sites (bifunctional effect).2,22,23  
Thus, the catalytic performance of Pt towards alcohol electrooxidation could be improved by adding oxygen enrichment  
metals to Pt-based bimetallic catalysts. 【纳米线有利于提高性能】

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On the other hand, one dimensional (1D) nanostructures also contribute to improving  
the performance of catalysts.24–29 【相比一维，三维结构优势，电子传输，提高活性、稳定性，由于高的结构稳定性，大的面积，连通性】

【相比一维，三维结构优势，电子传输，提高活性、稳定性，由于高的结构稳定性，大的面积，连通性】

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Essentially, three-dimensional  
(3D) nanostructures can further promote electron transfer and  
improve catalytic activity and stability to a greater extent than  
1D nanostructures, due to their higher structural stability,  
larger surface area and the connectivity of the profuse pore  
structure.16,30–32 【结合三维纳米线和合金化是对提高活性和稳定性是可行的】

【结合三维纳米线和合金化是对提高活性和稳定性是可行的】

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Consequently, it is feasible to combine 3D NWs  
and Pt-based bimetallic properties with oxygen enrichment  
metals to improve the catalytic activity and stability for the EOR  
and MOR.  
 【本文，我们制备了….】

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We prepared a new class of networked Pt–Sn NWs as highly  
active catalysts for alcohol electrooxidation. 【本文，多孔结构形成过程被观察】

【本文，多孔结构形成过程被观察】

[17] P. Song, X. Cui, Q. Shao, Y. Feng, X. Zhu, X. Huang, Networked Pt-Sn nanowires as efficient catalysts for alcohol electrooxidation, Journal of Materials Chemistry A, 2017, 5: 24626-24630.

The growth process  
of bimetallic aerogels with a 3D porous noble metal nanostructure could be readily observed. 【本文，相对一般颗粒结构，空泡多孔结构，开放连通的孔，大面积和缺陷】

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Compared with conventional nanoparticle nanostructures, aerogel nanostructures  
have the features of open interconnected pores with large  
surface areas and many defects.33–35 【本文，电催化活性被评估】

【本文，电催化活性被评估】

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The catalytic performance

of the networked Pt– Sn NWs was evaluated by studying the EOR  
and MOR in acid media. In particular, the optimized networked  
Pt6Sn3 NWs exhibited the best EOR and MOR activity compared  
with those of commercial Pt/C as well as other NWs demonstrating mass activities of up to 1.08 mA mgPt1 for the EOR and  
1.45 mA mgPt1 for the MOR in acid media, and specific activities of 1.40 mA cm 2 for the EOR and 1.88 mA cm 2 for the  
MOR. 【本文，电化学稳定性被确认】

【本文，电化学稳定性被确认】

[17] P. Song, X. Cui, Q. Shao, Y. Feng, X. Zhu, X. Huang, Networked Pt-Sn nanowires as efficient catalysts for alcohol electrooxidation, Journal of Materials Chemistry A, 2017, 5: 24626-24630.

The enhanced stability of the networked NWs of Pt6Sn3  
NWs was also confirmed by repeating CV sweeps for 500 cycles. 【】

## [18] Q. Shi, C. Zhu, C. Bi, H. Xia, M. H. Engelhard, D. Du, Y. Lin, Intermetallic Pd3Pb nanowire networks boost ethanol oxidation and oxygen reduction reactions with significantly improved methanol tolerance, Journal of Materials Chemistry A, 2017, 5: 23952-23959.

Introduction  
【由于。。。燃料电池具有很高的前景】

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[18] Q. Shi, C. Zhu, C. Bi, H. Xia, M. H. Engelhard, D. Du, Y. Lin, Intermetallic Pd3Pb nanowire networks boost ethanol oxidation and oxygen reduction reactions with significantly improved methanol tolerance, Journal of Materials Chemistry A, 2017, 5: 23952-23959.

From the long-term perspective, fuel cells are regarded as  
promising energy conversion devices due to their excellent  
theoretical sustainability, environmental friendliness and  
outstanding efficiency.1–3 【！Pt 具有高活性，在orr，小分子氧化，甲醇，甲酸等】

【！Pt 具有高活性，在orr，小分子氧化，甲醇，甲酸等】

[18] Q. Shi, C. Zhu, C. Bi, H. Xia, M. H. Engelhard, D. Du, Y. Lin, Intermetallic Pd3Pb nanowire networks boost ethanol oxidation and oxygen reduction reactions with significantly improved methanol tolerance, Journal of Materials Chemistry A, 2017, 5: 23952-23959.

Currently, there is no doubt that Pt  
and its alloys are under intensive studies because of their high  
electrocatalytic activity toward the oxygen reduction reaction  
(ORR) 4–12 and the oxidation of other small molecules such as  
methanol,13–15 formic acid16,17 and so on. 【Pt高成本，不稳定性】

【Pt高成本，不稳定性】

[18] Q. Shi, C. Zhu, C. Bi, H. Xia, M. H. Engelhard, D. Du, Y. Lin, Intermetallic Pd3Pb nanowire networks boost ethanol oxidation and oxygen reduction reactions with significantly improved methanol tolerance, Journal of Materials Chemistry A, 2017, 5: 23952-23959.

However, the development of Pt-based electrocatalysts is still challenging especially because of its high price and insufficient stability.18–20  
 【】Pd-based nanomaterials with lower prices are attracting  
considerable interest in electrochemistry because of their  
comparable or even superior bifunctional catalytic performances toward the ORR21–23 and other small molecules to Pt,  
especially in alkaline media.24–28 However, in addition to the  
insufficient stability of Pd-based electrocatalysts, there are  
another two critical issues that should also be addressed for  
their application in the ORR and ethanol oxidation reaction  
(EtOR): methanol-tolerance during the ORR when using methanol as the fuel at the anode and CO-poisoning during the  
EtOR. Firstly, methanol diffusion across the proton exchange  
membrane from the anode to cathode is a serious problem,29  
resulting in signicant deterioration of catalytic activity due to  
the so-called mixed potential and catalyst poisoning.30,31 Recent  
reports have indicated that bimetallic PdM structures possess  
enhanced methanol tolerance compared to Pt-based alloys.32,33  
CO poisoning is another serious problem that blocks the active  
sites, which can be released only when the as-formed Pd–COads  
is oxidized to CO2 at a large overpotential. It has been reported  
that the incorporation of Pb or Bi is an effective way to enhance  
CO-poisoning-tolerance due to the modied electronic structures, resulting in decreased adsorption energy of CO on the  
catalyst surface.34 Another reason is that they could provide  
adsorbed hydroxyl groups (OHads) due to their oxophilic properties, which is benecial in accelerating oxidation of COads at  
a much lower overpotential.35,36 【大量工作致力于设计成分，尺寸、形貌，发展高活性，稳定性催化剂】

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Therefore, numerous  
researchers are focusing on developing highly efficient Pd

based bimetallic or multimetallic electrocatalysts through  
engineering their compositions, sizes, shapes or morphologies  
for boosting their catalytic performances and improving their  
stabilities. 【从原子结构，合金成分设计。。提高活性，稳定性和选择性】

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Among them, from the perspective of intrinsic atomic  
structures, generation of intermetallic compounds is emerging  
as an attractive route for optimizing catalytic activities,  
extending long-term operation durabilities, and improving CO resistance abilities as well as enhancing the selectivity.37–39  
 【】Compared to disordered alloyed structures, intermetallic  
nanocrystals (IM-NCs) possess speci c atomic structures with  
predictable electronic and geometric effects and thus with  
a  nely adjusted d-band center and bonding strength toward  
the adsorption of intermediates for promoting catalytic activities.27,40–42 Besides, intermetallic compounds could also offer  
high selectivity that is urgently desirable for catalysts, which  
could be achieved through reducing the homoatomic coordination number of active sites.39 What's more, an extended lifetime of the intermetallic catalysts could also be realized due to  
the more negative enthalpy for the generation of intermetallics  
compared to that of alloys.39 【！！三维纳米线优势，多孔，贯通，自支撑】

【！！三维纳米线优势，多孔，贯通，自支撑】

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With respect to morphology,  
nanowire-based three-dimensional (3D) nanostructures, like  
aerogels,10,27,43–45 nanowire assemblies,46 nanowire networks  
(NNs),47,48 etc. , are very popular due to their high porosity and  
interconnected and self-supported 3D backbones.49 【1D纳米线，各向异性，有利于质量，电荷传输，增加表面积和稳定性，无碳基体腐蚀】

【1D纳米线，各向异性，有利于质量，电荷传输，增加表面积和稳定性，无碳基体腐蚀】

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It is well  
known that 1D nanowires with anisotropic structure could favor  
the mass and electron transfer rate, increase the active surface  
area and offer sufficient stability without carbon support  
corrosion issues.47,50–52【由于暴露原子，大量纳米线缺陷，扭结，台阶，晶界，高指数都可以作为活性位点，提高了活性】

【由于暴露原子，大量纳米线缺陷，扭结，台阶，晶界，高指数都可以作为活性位点，提高了活性】

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Besides, the tremendous defects of  
nanowires like the kinetic steps, grain boundaries and high  
index facets could serve as highly active sites due to the much  
more exposed Pd atoms on the edges for facilitating catalytic  
activity.50,53,54 【尽管，。。获得期望形貌催化剂存在挑战】

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[18] Q. Shi, C. Zhu, C. Bi, H. Xia, M. H. Engelhard, D. Du, Y. Lin, Intermetallic Pd3Pb nanowire networks boost ethanol oxidation and oxygen reduction reactions with significantly improved methanol tolerance, Journal of Materials Chemistry A, 2017, 5: 23952-23959.

Despite the aforementioned advantages of 3D intermetallic  
architectures, obtaining Pd-based IM-NCs rapidly with nely  
controlled morphologies and shapes at relatively low temperatures is still challenging.55 【本文，制备了纳米线网络，制备方法….】

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Here, for the rst time, we fabricated  
intermetallic Pd3Pb nanowire networks (IM-Pd3Pb NNs) with  
a one-step wet-chemical strategy at a low temperature ( i.e.  
170 C) in only 1 h. This one-pot approach adopted PVP as the  
capping agent, citric acid (CA) as the reducing agent and  
ethylene glycol (EG) as both the solvent and the reducing agent.  
 【本文、。。。显示了高的电化学性能】

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It is worth noting that the as-obtained IM-Pd3Pb NNs displayed  
signicantly improved ORR activity and stability comparable to  
commercial Pt/C with remarkably enhanced methanol tolerance. Besides, the electrochemically active surface area (ECSA)  
and mass activity (MA) toward the EtOR were 3.4-fold and 2-fold  
higher than those of Pd black, respectively, along with higher  
CO-resistance ability and long-term operation stability. 【本文，提高电化学性能原因，3d多孔、缺陷，纳米线，提供了活性位点，加速了离子传输】

【本文，提高电化学性能原因，3d多孔、缺陷，纳米线，提供了活性位点，加速了离子传输】

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The  
reasons for the outstanding electrochemical performances were  
partially attributed to the 3D hybrid pore systems along with the  
defect-enriched surface of ultrathin nanowires that provided  
abundant active sites and an accelerated mass diffusion rate for  
the ORR and EtOR. 【】More importantly, the formation of the  
intermetallic phase of Pd3Pb with nely congured atomic  
structures holds the key for enhancing the catalytic activity,  
stability and selectivity, as well as alleviating CO-poisoning due  
to the optimal electronic and geometric effects, and the stable  
chemical conguration. All these boosted electrocatalytic  
performances toward the ORR and EtOR indicated that IMPd  
3Pb NNs offer great opportunities for being employed as  
anode and cathode electrocatalysts for fuel cells.

## [19] Y. Shen, B. Gong, K. Xiao, L. Wang, In situ assembly of ultrathin PtRh nanowires to graphene nanosheets as highly efficient electrocatalysts for the oxidation of ethanol, ACS Applied Materials and Interfaces, 2017, 9: 3535-3543.

■ INTRODUCTION  
【由于…燃料电池受到关注】

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Being a highly efficient and environmentally friendly device to  
convert chemical energy stored in fuels to electrical power,  
polymer electrolyte membrane fuel cells (PEMFCs) have  
recently stimulated intense research.1 【高性能催化剂的缺乏阻碍了电池商业化】

【高性能催化剂的缺乏阻碍了电池商业化】

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Despite notable progress  
in PEMFCs, the widespread commercialization of PEMFCs is  
still impeded by the lack of high-performance electrocatalysts  
which show sufficient activity and durability for the oxidation of  
fuels at the anode and reduction of oxygen at the cathode.  
 【Pt纳米颗粒易溶解、迁移，粗化、，导致面积损失，活性和稳定性衰退】

【Pt纳米颗粒易溶解、迁移，粗化、，导致面积损失，活性和稳定性衰退】

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Currently, state-of-the-art catalysts in PEMFCs primarily consist  
of dispersive nanosized platinum-based particles (2 −5 nm)  
supported on carbon materials. The critical issue of these  
nanoparticulated catalysts is the poor durability. Zero-dimensional (0D) platinum-based nanoparticles (NPs) are susceptible  
to dissolution, migration, coalescence, and Ostwald ripening due  
to the high surface energy, which leads to a significant loss of  
electrochemically active surface areas (ECSAs) and subsequent  
activity decay during the long-term operation of PEMFCs.2 −5 【！！1D相比0D，1D纳米线高长径比，高稳定性，择优晶面，快速电子传输，有利于高活性】

【！！1D相比0D，1D纳米线高长径比，高稳定性，择优晶面，快速电子传输，有利于高活性】

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To  
address this issue, one promising strategy is to develop one dimensional (1D) nanostructured catalysts.6 −9 Compared with  
their 0D counterparts, 1D catalysts exhibit many inherent  
structural characteristics, i.e., high aspect ratios, high stability,  
preferential exposure of active crystal facets, and fast electron  
transport, which are highly beneficial to the performance of the  
catalysts.10 −12 【大量工作致力于纳米线制备，1D形貌有利于活性和稳定性，文献】

【大量工作致力于纳米线制备，1D形貌有利于活性和稳定性，文献】

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So far, numerous efforts have been directed in  
searching for 1D catalysts in PEMFCs.13 −28 For instance, Wong  
and co-workers conducted a significant amount of work to  
optimize the performance of 1D catalysts via delicate tailoring  
the elemental composition, surface structures and sizes of the  
anisotropic architectures.29 −32 They demonstrated that 1D  
anisotropic morphology was highly favorable to activity and  
durability of catalysts in PEMFCs. 【石墨烯纳米片具有更好的耐抗腐蚀性】

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Apart from the morphology of  
the active metallic component, the carbon support also affects the  
durability of catalysts. Carbon black, which is widely utilized as a  
catalyst support in PEMFCs, suffers from serious electrochemical  
corrosion, thus accelerating the segregation, dissolution, and  
detachment of metallic components.33 In contrast, graphene  
nanosheet (GNS) exhibits much better resistance to electrochemical corrosion because of its high conductivity and unique  
graphitized basal planes, rendering it to be an ideal alternative  
support in PEMFCs.34 【】  
Ethanol is considered to be one of the promising fuels in  
PEMFCs because of its sustainable production from fermentation processes, high energy density, and nontoxicity. To  
completely oxidize ethanol to carbon dioxide, the cleavage of  
C −C bonds is requisite, which, however, remains difficult on  
single Pt surface.35 To this end, several metallic elements such as  
Ru,36 Rh,37 and Ir38 were coupled with Pt to promote the

oxidation of ethanol via the so-called bifunctional and ligand  
effects. Of these elements, Rh is regarded as one of most effi cient  
components to facilitate the cleavage of the C − C bonds at lower  
potentials. It was reported that Rh was more effective to stabilize  
the metal – CH2CH2O intermediates during ethanol oxidation in  
comparison with Pt because of the high-lying d-band and more  
unoccupied d-states.35 In addition, the alloying of Rh with Pt was  
accompanied by an electron transfer from Rh to Pt, resulting in  
more d-states of Rh and a downshift in the d-states of Pt. Such  
synergistic effects afforded moderate bonding to ethanol,  
intermediates, and products, which facilitated C −C bond  
breaking.35 Previous studies demonstrated that PtRh alloys  
showed exceptional efficiency toward ethanol oxidation.39  
【本文，我们报道了纳米线制备方法….】

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Herein, we report a simple approach to in situ assembly of  
PtRh nanowires (NWs) to GNS as a high-performance  
electrocatalyst for the oxidation of ethanol. 【本文，催化剂的优势在于结构由，纳米线。。。构成】

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The prominent  
advantage of the PtRh catalyst reported in this work lies in its  
structural features, which consist of ultrafine 1D PtRh nanowires  
supported by two-dimensional (2D) GNSs. 【本文，电化学活性和稳定性】

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The as-prepared  
PtRh NW decorated GNS (denoted as PtRh NW/GNS) exhibits  
outstanding activity and durability toward ethanol oxidation  
because of the combination of the structural merits of the two  
components. 【】

## [20] W. Shen, B. Wu, F. Liao, B. Jiang, M. Shao, Optimizing the hydrogen evolution reaction by shrinking Pt amount in Pt-Ag/SiNW nanocomposites, International Journal of Hydrogen Energy, 2017, 42: 15024-15030.

Introduction  
【能源危机，环境污染】

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Recently, we have to face the increasingly serious environmental pollution and the upcoming energy depletion on account of the high dependence on fossil fuels. 【氢能的优势】

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Hydrogen has  
been considered as an ideal candidate in the future to replace  
fossil fuels due to its properties of carbon-free release, sustainability and renewability [1e4]. 【电解水受到关注】

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Nowadays, electrolysis of  
water, one of the simplest ways for hydrogen evolution reaction (HER), has drawn worldwide attention [5,6]. The key issue  
for HER is to search for the cheap electrocatalysts with  
excellent activity in order to produce hydrogen massively and efficiently.  
 【Pt 高效催化剂】

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Up to now, noble metals, such as platinum (Pt), have been  
demonstrated to be the most effective electrocatalysts for HER  
[7e9]. 【pt资源匮乏，高成本】

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[20] W. Shen, B. Wu, F. Liao, B. Jiang, M. Shao, Optimizing the hydrogen evolution reaction by shrinking Pt amount in Pt-Ag/SiNW nanocomposites, International Journal of Hydrogen Energy, 2017, 42: 15024-15030.

However, their scarcity and high cost prevented wide  
range application [10e12]. 【】At present, inorganic catalysts  
including MoS2 [13e15], WS2 [16], WC [17], MoC2 and MoC [18]  
have become a focus of concern because of their abundance  
and low costs. Nevertheless, their electrocatalytic performance was still regarded as inferior to Pt-based catalysts,  
which makes decreasing the Pt usage an ultimate goal for the  
design request of electrocatalysts to achieve low-cost  
hydrogen production. Supported carriers are wildly adopted  
in the high efficient electrocatalysts for HER. For example,  
silicon nanowires (SiNWs), achieved via numerous methods  
[19,20], can effectively avoid the aggregation of nanoparticles

grown on their surfaces, increasing the active sites of the  
catalysts [21,22]. Moreover, SiNWs-supported noble metals  
also turned out to show enhancement of the electrocatalytic  
activity due to the low desorption energy of hydrogen of  
SiNWs [22].  
 【本文，报道了一个pt减少使用量的方法….】

【本文，报道了一个pt减少使用量的方法….】

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Here, we developed a method to dramatically decrease the  
usage of Pt via adding the low-cost Ag as a co-catalyst and the  
inexpensive silicon nanowires (SiNWs) as efficient electrocatalyst carriers. 【本文，制备催化剂利用到Ag的主要优势】

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[20] W. Shen, B. Wu, F. Liao, B. Jiang, M. Shao, Optimizing the hydrogen evolution reaction by shrinking Pt amount in Pt-Ag/SiNW nanocomposites, International Journal of Hydrogen Energy, 2017, 42: 15024-15030.

Although pure Ag has a low activity in the  
HER, it has good chemical stability and be adopted as excellent  
catalysts [23]. In addition, Ag has a lattice constant similar to  
that of Pt [24], which may be beneficial to reduce the stress of  
Pt-Ag bimetallic and improve their stability. Pt-Ag/SiNW  
composites with different dosages of Pt were synthesized  
and their catalysis in HER was conducted in the acidic medium. 【本文，电化学性能】

【本文，电化学性能】

[20] W. Shen, B. Wu, F. Liao, B. Jiang, M. Shao, Optimizing the hydrogen evolution reaction by shrinking Pt amount in Pt-Ag/SiNW nanocomposites, International Journal of Hydrogen Energy, 2017, 42: 15024-15030.

The results showed that the optimal composition of PtAg/SiNW composites is 4.1 (Pt): 21.5 (Ag): 74.4 (Si) in mass ratio.  
With such a low amount of Pt, the Pt-Ag/SiNW catalyst  
exhibited exciting hydrogen evolution reaction performance,  
whose turnover frequency (TOF) is 6.3H2Pt 1s 1 at 0.2 V vs.  
RHE, 2.7 times as large as that of 40 wt% Pt/C.【】

## [21] S. Y. Ma, H. H. Li, B. C. Hu, X. Cheng, Q. Q. Fu, S. H. Yu, Synthesis of Low Pt-Based Quaternary PtPdRuTe Nanotubes with Optimized Incorporation of Pd for Enhanced Electrocatalytic Activity, Journal of the American Chemical Society, 2017, 139: 5890-5895.

■ INTRODUCTION  
【燃料电池具有潜力】

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Direct methanol fuel cells (DMFCs) hold the potential to be   
promising power conversion devices for portable and mobile  
applications.1,2 【Pt的高成本，易毒化】

【Pt的高成本，易毒化】

[21] S. Y. Ma, H. H. Li, B. C. Hu, X. Cheng, Q. Q. Fu, S. H. Yu, Synthesis of Low Pt-Based Quaternary PtPdRuTe Nanotubes with Optimized Incorporation of Pd for Enhanced Electrocatalytic Activity, Journal of the American Chemical Society, 2017, 139: 5890-5895.

However, the high loadings and the high cost of  
Pt are key obstacles for their broad deployment and widespread  
commercialization. Moreover, the pure Pt catalysts are prone to  
poisoning by the intermediates occupying the active sites and  
blocking new reactants adsorption.3 −5 【大量的研究致力于pt合金化。】

【大量的研究致力于pt合金化。】

[21] S. Y. Ma, H. H. Li, B. C. Hu, X. Cheng, Q. Q. Fu, S. H. Yu, Synthesis of Low Pt-Based Quaternary PtPdRuTe Nanotubes with Optimized Incorporation of Pd for Enhanced Electrocatalytic Activity, Journal of the American Chemical Society, 2017, 139: 5890-5895.

Intensive research efforts  
have been focused on developing promising catalysts via  
alloying Pt with transition metals, modifying electronic  
structure of Pt, and reducing Pt consumption.6 −8 【】However,  
the conventional alloyed or heterogeneous catalysts prepared so  
far face limitations in terms of composition or structural  
stability under the harsh conditions. 【Pt颗粒，易溶解，团聚，减少了面积，降低了性能】

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They usually undergo Pt  
dissolution or nanoparticle (NP) aggregation after potential  
cycling, resulting in active surface area loss and decreased  
methanol oxidation reaction (MOR) performance over  
time.9 −11 【期望发展成分稳定，形貌可控的催化剂，提高活性和稳定性】

【期望发展成分稳定，形貌可控的催化剂，提高活性和稳定性】

[21] S. Y. Ma, H. H. Li, B. C. Hu, X. Cheng, Q. Q. Fu, S. H. Yu, Synthesis of Low Pt-Based Quaternary PtPdRuTe Nanotubes with Optimized Incorporation of Pd for Enhanced Electrocatalytic Activity, Journal of the American Chemical Society, 2017, 139: 5890-5895.

Therefore, it is desirable to develop multimetallic  
catalysts with stable and active components through the direct  
metal −metal interaction by a shape-controlled synthesis  
method, linking the component effect and well-defined surface  
to enhance the activity and stability.  
 【催化剂稳定性，如Pt溶解，基底腐蚀，团聚，与结构成分有很大关系】

【催化剂稳定性，如Pt溶解，基底腐蚀，团聚，与结构成分有很大关系】

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The stability of catalysts, such as Pt dissolution, support  
corrosion, and particle aggregation, is closely related to the  
structure and composition.12,13 The control on nanomaterial  
composition and structure provides a sensitive knob to  
optimize the electrocatalytic performance.14,15 【】Au is a famous  
element for its stabilizing effect on enhancing component  
stability and thus electrocatalytic durability, as well as Pd to a  
certain extent.16 −18 For electrocatalysts, surface oxidation may  
induce active atoms dissolution. Au or Pd atoms play an  
important role in protecting low-coordination sites, active Pt  
sites, and certain facets from being oxidized, due to their higher  
reduction potential.19 −22 The Au or Pd in the catalysts usually  
provides a bifunctional effect in improving the catalyst activity  
by introducing a strain or tuning the electronic properties and  
protecting active sites during potential cycling. For MOR with  
multielectron transferring, desorption of the covered intermediates CO  
ad from the surface is also important for liberating  
the active sites. Ru-based catalysts have been recognized as  
effective MOR catalysts due to Ru atoms that served as a water  
activator and may lower the water dissociation potential,  
providing more OHad to accelerate COad oxidation.23 −26 Many  
aspects of the component effect (heteroatomic interaction) on  
MOR so far have been well understood based on the bimetallic  
Pt-based alloy or heterogeneous catalysts, leading us to explore  
ternary or quaternary catalysts.  
【本文，我们报道了纳米管催化剂的设计和催化性能】

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[21] S. Y. Ma, H. H. Li, B. C. Hu, X. Cheng, Q. Q. Fu, S. H. Yu, Synthesis of Low Pt-Based Quaternary PtPdRuTe Nanotubes with Optimized Incorporation of Pd for Enhanced Electrocatalytic Activity, Journal of the American Chemical Society, 2017, 139: 5890-5895.

Herein, we report the design and electrocatalytic performance of quaternary PtPdRuTe nanotubes (NTs) catalysts for  
MOR with low Pt content via galvanic replacement reaction at  
the expense of ultrathin Te nanowires (NWs). 【本文，制备催化剂结构特点】

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[21] S. Y. Ma, H. H. Li, B. C. Hu, X. Cheng, Q. Q. Fu, S. H. Yu, Synthesis of Low Pt-Based Quaternary PtPdRuTe Nanotubes with Optimized Incorporation of Pd for Enhanced Electrocatalytic Activity, Journal of the American Chemical Society, 2017, 139: 5890-5895.

Fine tuning of  
the molar ratio of Pt and Pd precursors affords PtPdRuTe NTs  
with controlled compositions. 【】As quaternary Pt-based catalysts,

each component of the NTs fulfills an important role in the  
electrocatalysis. The unreacted Te atoms support the NT  
skeleton and minimize the loading of the other three precious  
metals. The Pt atoms served as the active sites for MOR to  
dehydrogenated methanol forming Pt-CO, while the more  
oxyphilic Ru sites facilitate the adsorption of oxygen species  
forming Ru − OH at a lower potential, preferentially oxidizing  
C O  
a d to produce CO2 and refreshing new active sites  
(bifunctional mechanism). The introduction of a few Pd  
atoms into the NT catalysts improved the surface reactivity  
during the long-term stability tests due to the higher reduction  
potential and modified electronic structure of Pt. In comparison  
with the ternary PtRuTe catalysts, quaternary system is also  
expected to display not only great synergic effects of each  
component to further boost the catalytic activities but also new  
properties and stability of the catalysts. Pd is known as a stable  
element for its stabilization effect to decrease Pt oxidation and  
corrosion by up-shifting the dissolution potential of Pt. The  
resultant quaternary component catalysts show enhanced  
catalytic activity and durability toward the MOR

## [22] J. Lai, S. Guo, Design of Ultrathin Pt-Based Multimetallic Nanostructures for Efficient Oxygen Reduction Electrocatalysis, Small, 2017, 13.

1. Introduction  
【Pt缓慢的orr反应速率，资源少，阻碍商化】

【Pt缓慢的orr反应速率，资源少，阻碍商化】

[22] J. Lai, S. Guo, Design of Ultrathin Pt-Based Multimetallic Nanostructures for Efficient Oxygen Reduction Electrocatalysis, Small, 2017, 13.

Platinum (Pt) represents the essential element for catalyzing  
the oxygen reduction reaction (ORR).[1–9] However, its sluggish  
ORR rate and the limited reserves on the earth are becoming  
the primary limiting factor in the commercialization of fuel  
cell devices.[10–14] 【大量工作致力于提高活性，减少用量】

【大量工作致力于提高活性，减少用量】

[22] J. Lai, S. Guo, Design of Ultrathin Pt-Based Multimetallic Nanostructures for Efficient Oxygen Reduction Electrocatalysis, Small, 2017, 13.

Extensive efforts have been devoted to both  
improving the intrinsic activity of Pt-based electrocatalysts and  
reducing the Pt usage for ORR without compromising fuel

cell performance. 【实验和理论表明了结构对提高活性很重要】

【实验和理论表明了结构对提高活性很重要】

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The combined experimental and theoretical studies provide the  
important clues for revealing the structure–function relationship and achieving  
the enhanced ORR performance.[15–19] 【】 In  
order to facilitate the maximized catalytic  
activity for ORR, the adsorption energies  
of reactive intermediates and surface coverage by spectator oxygenated species as  
well as specifially adsorbed anions on the  
catalyst surface should be well balanced.  
The better ORR catalysts should bind  
oxygen more weakly than that of Pt, and  
more strongly than that of Pt3V or Pt3Ti.  
In this regard, Ni, Co, and Fe are found  
to be the effective alloying elements with  
Pt for enhancing ORR intrinsic activity.[15]  
This intrisic activity enhancement is originated from the downshift of the d-band  
center of Pt in the alloyed PtM (M Fe,  
Co, Ni) structure, resulting in a decrease  
of the bonding strength between Pt and the spectator oxygenated species. Therefore, alloying Pt with some transition metals  
(e.g., Cu, Fe, Co, Ni) or forming a less expensive core/Pt shell  
structure has become the attractive strategy to reduce the  
required usage of Pt, and meantime achieve much enhanced  
ORR electrocatalytic activity and durability over the state-of-theart carbon supported platinum (Pt/C) catalyst.[15,18,20–38] Besides  
multimetallic composition, ultrathin Pt-based multimetallic  
nanostructures are recently attracting more extensive attention.[39–44] We designate the concept “ultrathin” specifially as at  
least 1D of traditional nanomaterials to sub-2 nm. 【相比实心和块体，超薄尺寸有很大的面积】

【相比实心和块体，超薄尺寸有很大的面积】

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In comparison with solid or bulk counterparts, ultrathin size can lead to  
more exposed surface atoms with more active sites. 【】Moreover,  
ultrathin shell of core/shell structure can well tune the lattice  
compressive/tensile strain of surface atoms that increases the  
intrinsic activity of each active site. 【纳米材料超薄特点使其成为具有前景的催化剂】

【纳米材料超薄特点使其成为具有前景的催化剂】

[22] J. Lai, S. Guo, Design of Ultrathin Pt-Based Multimetallic Nanostructures for Efficient Oxygen Reduction Electrocatalysis, Small, 2017, 13.

These important features of  
multimetallic nanomaterials with the characteristic of ultrathin  
sizes make them very promising catalysts for high effiient  
ORR catalytic applications. 【超薄纳米结构具有优势，合成存在挑战】

【超薄纳米结构具有优势，合成存在挑战】

[22] J. Lai, S. Guo, Design of Ultrathin Pt-Based Multimetallic Nanostructures for Efficient Oxygen Reduction Electrocatalysis, Small, 2017, 13.

However, despite the obvious advantages of ultrathin Pt-based multimetallic nanostructures, the  
key challenge has been the generation of active ultrathin Ptbased nanostructure using reliable synthetic techniques. It is  
not an easy task to synchronously control the nucleation and  
growth of diverse metals with especially big differences in  
redox potentials, which makes ultrathin Pt-based multimetallic  
nanostructures hard to be synthesized. 【】  
This review will summarize the latest progress in colloid  
methods for the preparation of 0D, 1D, 2D and 3D ultrathin

Pt-based multimetallic nanostructures for boosting ORR electrocatalysis. The key structural factors, such as the composition,  
shape, and structure, which govern the electrocatalytic activity  
and stability will be highlighted. We will start with new synthetic methods for multimetallic core/shell nanoparticles (NPs)  
with ultrathin shell size for promoting ORR catalysis. Then,  
recent important advances in tuning multimetallic nanowires  
(NWs) by forming alloy and core/shell structure with well-controlled surface are presented to better improve the ORR activity  
and stability. We will further highlight more recent important  
breakthrough in using wet-chemical methods for controlled  
synthesis of Pt-based 2D nanosheets with well-defied structure and surface strain for enhancing the activity and stability  
of ORR. Last but not least, the ultrathin Pt-based multimetallic  
nanoframes that feature 3D molecularly accessible surfaces will  
be discussed for achieving highly effiient ORR catalysis. Some  
perspectives and challenges will be given on how to develop  
more practical oxygen reduction electrocatalysts featuring high  
stability, low cost, and enhanced activity.

## [23] H. Huang, K. Li, Z. Chen, L. Luo, Y. Gu, D. Zhang, C. Ma, R. Si, J. Yang, Z. Peng, J. Zeng, Achieving Remarkable Activity and Durability toward Oxygen Reduction Reaction Based on Ultrathin Rh-Doped Pt Nanowires, Journal of the American Chemical Society, 2017, 139: 8152-8159.

■ INTRODUCTION  
【燃料电池具有发展潜力】

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[23] H. Huang, K. Li, Z. Chen, L. Luo, Y. Gu, D. Zhang, C. Ma, R. Si, J. Yang, Z. Peng, J. Zeng, Achieving Remarkable Activity and Durability toward Oxygen Reduction Reaction Based on Ultrathin Rh-Doped Pt Nanowires, Journal of the American Chemical Society, 2017, 139: 8152-8159.

Proton exchange membrane fuel cells (PEMFCs) have been  
recognized as a promising clean energy conversion technology  
for efficient power delivery in transportation and mobile  
devices.1 −3 【Pt的缺点】

【Pt的缺点】

[23] H. Huang, K. Li, Z. Chen, L. Luo, Y. Gu, D. Zhang, C. Ma, R. Si, J. Yang, Z. Peng, J. Zeng, Achieving Remarkable Activity and Durability toward Oxygen Reduction Reaction Based on Ultrathin Rh-Doped Pt Nanowires, Journal of the American Chemical Society, 2017, 139: 8152-8159.

However, the commercialization of such technology  
has so far been hampered by the prohibitive cost of associated  
devices, because a large amount of precious platinum (Pt) is  
required as catalyst to mitigate the sluggish kinetics of the  
oxygen reduction reaction (ORR) at the cathode.4−10 【降低成本，提高活性的策略】

【降低成本，提高活性的策略】

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One  
solution to lower the cost is to reduce the usage of Pt catalyst in  
PEMFCs by improving the mass activity toward ORR. To this  
end, a variety of strategies have emerged to enhance the  
utilization efficiency (UE) of Pt, e.g., reducing the particle  
size,11 −15 synthesizing a core −shell structure with a cheaper  
metal as the core,16 −18 and preparing hollow nanostructures.19 −22 【】Besides, another method to improve the mass activity is to boost the specific activity of a catalyst by incorporating a transition metal into Pt-based catalysts, 23 −26  
shaping the exposed facets,23,27 tuning the surface strain,28 −31  
and so on. The principle of these methods, intrinsically, was to  
optimize the binding energy of oxygenated species.32 Although  
a number of Pt-based catalysts with excellent mass activities  
have been successfully reported, most of these catalysts suffered  
from the relatively mediocre durability. For example, the  
electrochemical active surface area (ECSA) of Pt octahedral  
nanocages reduced by 23% after 10 000 cycles.20 【Pt基催化剂不稳定原因，热动力学不稳定结构，活性和稳定性存在矛盾】

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The  
insufficient durability of these Pt-based catalysts is ascribed to  
the thermodynamically unstable structures that are generally  
needed for high mass activities, so it seems that there is a  
conflict between high mass activity and superior durability.33【！减少成本的方法，提高pt稳定性，调控维度是有效的方法去调控稳定性】

【！减少成本的方法，提高pt稳定性，调控维度是有效的方法去调控稳定性】

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Indeed, another solution to reduce the cost of PEMFCs is to  
improve the long-term durability of Pt-based electrocatalysts at  
the cathode. Tuning the dimension of Pt-based catalysts  
represents an effective strategy to modify the durability by  
varying the symmetry and surface area contiguous to carbon  
support. 【相比0维，纳米线优势及稳定原因】

【相比0维，纳米线优势及稳定原因】

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For instance, Pt-based catalysts with one-dimensional  
(1D) structures, such as Pt nanowires (NWs), exhibited better  
durability toward ORR than that of their zero-dimensional  
counterparts.34−36 The higher stability is due to the asymmetry  
of the structure which suppresses physical ripening process, and  
a higher surface area in contact with the carbon support which  
strengthens the interaction between NWs and carbon support.  
【】In addition, the incorporation of specific metals into Pt-based

catalysts has recently been proved favorable to improve the  
durability.37,38 For example, decorating Pt catalysts with Au  
clusters contributed to resisting the dissolution of Pt atoms  
under potential cycling regimes, which thus greatly enhanced  
their ORR durability.37 Besides, adding a small amount of Rh  
into Pt −Ni nanoparticles was reported to help stabilize the  
octahedral morphology and enhance the catalytic durability.38  
Inspired by the above analysis, we anticipated achieving a  
superior catalyst by combining the features of high UE of Pt  
atoms, anisotropic 1D nanostructure, and doping of Rh atoms.  
 【本文，我们报道了。。纳米线结构催化剂。。，结合了。。。的结构特点】

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[23] H. Huang, K. Li, Z. Chen, L. Luo, Y. Gu, D. Zhang, C. Ma, R. Si, J. Yang, Z. Peng, J. Zeng, Achieving Remarkable Activity and Durability toward Oxygen Reduction Reaction Based on Ultrathin Rh-Doped Pt Nanowires, Journal of the American Chemical Society, 2017, 139: 8152-8159.

Herein, we report a remarkable ORR catalyst with both excellent mass activity and durability based on sub 2 nm thick  
Rh-doped Pt NWs, which combine the merits of high UE of Pt  
atoms, anisotropic one-dimensional nanostructure, and doping  
of Rh atoms. Because of the ultrathin diameter of 1.3 nm, the  
UE of Pt atoms for the NWs was estimated to be as high as  
48.6% using an approximate atomic model. 【本文，电化学活性和稳定性】

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[23] H. Huang, K. Li, Z. Chen, L. Luo, Y. Gu, D. Zhang, C. Ma, R. Si, J. Yang, Z. Peng, J. Zeng, Achieving Remarkable Activity and Durability toward Oxygen Reduction Reaction Based on Ultrathin Rh-Doped Pt Nanowires, Journal of the American Chemical Society, 2017, 139: 8152-8159.

The Rh-doped Pt NWs/C catalyst exhibits the great improvement in both mass  
activity and durability toward ORR with respect to those of Pt  
NWs/C catalyst and commercial Pt/C catalyst. 【通过形貌，成分表征解释活性，稳定性的提高】

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The origin of  
enhancement in activity and durability was also elucidated by  
extended X-ray absorption fine structure (EXAFS) analysis and  
density functional theory (DFT) calculations.【】

## [24] Y. Z. Guo, S. Y. Yan, C. W. Liu, T. F. Chou, J. H. Wang, K. W. Wang, The enhanced oxygen reduction reaction performance on PtSn nanowires: The importance of segregation energy and morphological effects, Journal of Materials Chemistry A, 2017, 5: 14355-14364.

Introduction  
【ORR在燃料电池中是重要的反应】

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[24] Y. Z. Guo, S. Y. Yan, C. W. Liu, T. F. Chou, J. H. Wang, K. W. Wang, The enhanced oxygen reduction reaction performance on PtSn nanowires: The importance of segregation energy and morphological effects, Journal of Materials Chemistry A, 2017, 5: 14355-14364.

The oxygen oxidation reaction (ORR) is an important process in  
the promising low-temperature power devices of proton exchange  
membrane fuel cells (PEMFCs) and metal– air batteries . 1– 4  
 【】Pt-Based electrodes, which can facilitate the four-electron  
reduction reaction (O2 + 4H+ + 4e / 2H2O) through the most  
efficient pathway in the ORR and avoid corrosion in acidic and  
alkaline media under the ORR operation conditions, have been  
widely investigated to better improve their activity and stability.  
The ORR activity on Pt-based catalysts is constrained by the  
high overpotential in the low-current part because the oxygencontaining species (OCS) is hard to remove and blocks Pt  
active sites. 5– 9 Various studies focused on introducing other  
elements to lower the oxophilicity of Pt electrodes and solve this  
slow-kinetics problem. Most of them investigated the bimetallic  
catalysts of PtM, where M refers to transition metals of 3d10  
(Ti,3,11 V,3 Fe,3,12–14 Co,3,12–18 Ni3,13,14,16,19,20 and Cu16,18,21–24), 4d  
(Pd18,25,26 and Ag25) and 5d (Au18,25,27,28). The studies concluded  
that the oxophilicity can be well adjusted through geometric  
(strain-lattice), ligand (electronic) and ensemble effects.21,29,30 Pt  
loaded with 3d and most of the 4d elements with smaller radii  
than that of Pt preferentially forms Pt-shelled structures. The  
surface Pt element has weak oxophilicity to improve the ORR  
activity due to its reduced lattice parameters and lower energy  
d bands, so-called the geometric and ligand effects. On the  
other hand, Pt loaded with larger and less reactive elements, e.g.  
Ag and Au, is thermodynamically stable to form a Pt-core  
structure. The loaded elements on the surface can weaken the  
adsorption of OCS and enhance the activity through the  
ensemble effect. The bimetallic PtMs with the transition metals  
indeed exhibit much better activity compared with commercial  
Pt/C electrodes; however, their stability still needs to be  
upgraded.  
The ORR stability can be well predicted from the segregation  
energy calculations for both clean (Eseg) and OCS adsorbed (EsegOCS) PtM,18,25,31,32 corresponding to the stability of the catalysts  
before and under ORR operation. Our previous study25  
demonstrated that although PtAu has the highest activity  
among three Pt-based noble catalysts, the computational Eseg/  
E  
seg-OCS as well as the experimental durability test conrm that  
PtAg has the best ORR stability, suggesting the importance of  
materials screening and catalyst design through computations.  
In this study, segregation energy calculations have been  
applied to study the potentials of various Pt-based catalysts  
toward the ORR and PtSn catalysts which have been widely

applied as methanol/ethanol oxidation reaction (MOR/EOR)  
catalysts are selected as promising catalysts for the ORR.  
Apart from this, PtSn nanomaterials including nanoparticles  
(NPs) and nanowires (NWs) are prepared in order to take  
advantage of ensemble and morphology effects to further  
enhance their ORR performance. 【本文，电化学活性】

【本文，电化学活性】

[24] Y. Z. Guo, S. Y. Yan, C. W. Liu, T. F. Chou, J. H. Wang, K. W. Wang, The enhanced oxygen reduction reaction performance on PtSn nanowires: The importance of segregation energy and morphological effects, Journal of Materials Chemistry A, 2017, 5: 14355-14364.

By the combination of Sn  
modi cation and aspect ratio alteration, PtSn NWs show  
promoted ORR durability with a decay of 24% aer accelerated  
durability tests (ADTs) of 10 000 cycles when compared with Pt  
NWs with a decay of 83%.【】

## [25] N. Zhang, S. Guo, X. Zhu, J. Guo, X. Huang, Hierarchical Pt/PtxPb Core/Shell Nanowires as Efficient Catalysts for Electrooxidation of Liquid Fuels, Chemistry of Materials, 2016, 28: 4447-4452.

■ INTRODUCTION  
 【燃料电池是高效的转换装置】

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Fuel cells are highly efficient renewable devices in converting chemical energy into electric power via the electrochemical process.  
1,2 【催化剂是最重要的组成】

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[25] N. Zhang, S. Guo, X. Zhu, J. Guo, X. Huang, Hierarchical Pt/PtxPb Core/Shell Nanowires as Efficient Catalysts for Electrooxidation of Liquid Fuels, Chemistry of Materials, 2016, 28: 4447-4452.

The catalysts are the most important components of  
fuel cells. 3−5 【Pt高效催化剂】

【Pt高效催化剂】

[25] N. Zhang, S. Guo, X. Zhu, J. Guo, X. Huang, Hierarchical Pt/PtxPb Core/Shell Nanowires as Efficient Catalysts for Electrooxidation of Liquid Fuels, Chemistry of Materials, 2016, 28: 4447-4452.

The rare and precious Pt is believed to be the  
most promising metal catalyst.6 −10 【为减少用量，提高活性的策略】

【为减少用量，提高活性的策略】

[25] N. Zhang, S. Guo, X. Zhu, J. Guo, X. Huang, Hierarchical Pt/PtxPb Core/Shell Nanowires as Efficient Catalysts for Electrooxidation of Liquid Fuels, Chemistry of Materials, 2016, 28: 4447-4452.

To minimize the consumption and improve the utilization efficiency of Pt in fuel  
cells, reducing the size of the nanoparticles (NPs) and  
substituting Pt with a much less expensive transition metal  
are the most widely used strategies.11 −14 【Pt缺点】

【Pt缺点】

[25] N. Zhang, S. Guo, X. Zhu, J. Guo, X. Huang, Hierarchical Pt/PtxPb Core/Shell Nanowires as Efficient Catalysts for Electrooxidation of Liquid Fuels, Chemistry of Materials, 2016, 28: 4447-4452.

However, the major  
limitations of previously created Pt-based catalysts are still their  
high cost, moderate activity, and low durability during the  
electrocatalytic process, largely impeding the large-scale  
commercialization of fuel cells.15 −18  
 【纳米线优势】

【纳米线优势】

[25] N. Zhang, S. Guo, X. Zhu, J. Guo, X. Huang, Hierarchical Pt/PtxPb Core/Shell Nanowires as Efficient Catalysts for Electrooxidation of Liquid Fuels, Chemistry of Materials, 2016, 28: 4447-4452.

Recently, one-dimensional (1D) noble metal nanostructures  
such as nanowires (NWs) and nanorods have been highlighted  
as a new class of electrocatalysts for enhancing both the activity  
and the durability of different catalytic reactions because they  
have some obvious advantages such as inherent anisotropic  
structure, high flexibility, high surface area, and high  
conductivity.19 −23 【纳米线光滑表面导致活性不高，对此，3D分级结构将有利于高性能】

【纳米线光滑表面导致活性不高，对此，3D分级结构将有利于高性能】

[25] N. Zhang, S. Guo, X. Zhu, J. Guo, X. Huang, Hierarchical Pt/PtxPb Core/Shell Nanowires as Efficient Catalysts for Electrooxidation of Liquid Fuels, Chemistry of Materials, 2016, 28: 4447-4452.

Despite the great potentials, the biggest  
challenging issue of previously reported Pt-based NWs is they  
have a smooth surface, leading to very limited electrocatalytic  
performance enhancements.24,25 In this regard, the realization  
of 3D hierarchical Pt-based NWs with a precise surface and  
structure would be extremely beneficial for the creation of high performance Pt-based catalysts toward liquid fuels electrooxidation. 【】 However, compared with the established Pd/Pt and  
Au/Pt bimetallic NWs with dendritic morphology, creating  
hierarchical PtPb-based NWs with high surface area shows  
limited success mainly due to the lack of a suitable synthetic  
method in controlling the reduction process of the Pb  
precursor.  
26 −29  
【本文，这里，我们报道了。。。分级结构合成方法】

【本文，这里，我们报道了。。。分级结构合成方法】

[25] N. Zhang, S. Guo, X. Zhu, J. Guo, X. Huang, Hierarchical Pt/PtxPb Core/Shell Nanowires as Efficient Catalysts for Electrooxidation of Liquid Fuels, Chemistry of Materials, 2016, 28: 4447-4452.

Herein, we report a facile strategy for preparing a new class of hierarchical Pt/PtxPb core/shell NWs as highly efficient  
electrocatalysts for liquid fuels electrooxidation. 【本文，纳米线结构的特点】

【本文，纳米线结构的特点】

[25] N. Zhang, S. Guo, X. Zhu, J. Guo, X. Huang, Hierarchical Pt/PtxPb Core/Shell Nanowires as Efficient Catalysts for Electrooxidation of Liquid Fuels, Chemistry of Materials, 2016, 28: 4447-4452.

The most  
important feature of our new Pt/PtxPb core/shell NWs is that  
they integrate a 1D structure, core/shell structure, alloy effect,  
and high surface area. 【本文，电化学活性】

【本文，电化学活性】

[25] N. Zhang, S. Guo, X. Zhu, J. Guo, X. Huang, Hierarchical Pt/PtxPb Core/Shell Nanowires as Efficient Catalysts for Electrooxidation of Liquid Fuels, Chemistry of Materials, 2016, 28: 4447-4452.

They exhibit the enhanced electrocatalytic activities toward methanol oxidation reaction (MOR)  
and ethanol oxidation reaction (EOR) relative to the PtPb0.21  
NPs and the commercial Pt/C (20 wt %, Pt particle size: 2 −5  
nm, Johnson Matthey) catalyst. As a consequence, the  
optimized PtPb0.27 NWs have the mass activity of 1.21 A/  
mgPt for MOR and 0.89 A/mgPt for EOR, which are 5.8 and 4.8  
times higher than those of commercial Pt/C catalyst,  
respectively.【本文，电化学稳定性】

【本文，电化学稳定性】

[25] N. Zhang, S. Guo, X. Zhu, J. Guo, X. Huang, Hierarchical Pt/PtxPb Core/Shell Nanowires as Efficient Catalysts for Electrooxidation of Liquid Fuels, Chemistry of Materials, 2016, 28: 4447-4452.

They are also generally much more stable than  
the PtPb 0.21 NPs, suggesting that such hierarchical Pt-Pb NWs  
can be used as active and stable electrocatalysts for future  
practical fuel cells and beyond. 【】

## [26] C. Zhang, L. Xu, Y. Yan, J. Chen, Controlled synthesis of Pt nanowires with ordered large mesopores for methanol oxidation reaction, Scientific Reports, 2016, 6.

【由于。。。燃料电池受到关注】

【由于。。。燃料电池受到关注】

[26] C. Zhang, L. Xu, Y. Yan, J. Chen, Controlled synthesis of Pt nanowires with ordered large mesopores for methanol oxidation reaction, Scientific Reports, 2016, 6.

The direct methanol fuel cells (DMFCs) have attracted great attention as promising candidates for portable,  
transportation and mobile applications because of their high power densities and high energy-conversion efiiencies1,2. 【阳极是燃料电池的重要组成】

【阳极是燃料电池的重要组成】

[26] C. Zhang, L. Xu, Y. Yan, J. Chen, Controlled synthesis of Pt nanowires with ordered large mesopores for methanol oxidation reaction, Scientific Reports, 2016, 6.

The anode, where methanol is oxidized to produce carbon dioxide, protons and electrons, is a key  
component of DMFCs3. 【Pt高效催化剂】

【Pt高效催化剂】

[26] C. Zhang, L. Xu, Y. Yan, J. Chen, Controlled synthesis of Pt nanowires with ordered large mesopores for methanol oxidation reaction, Scientific Reports, 2016, 6.

Until now, nanostructured Pt materials have been recognized among the most active  
anode catalysts for methanol oxidation due to their high surface areas, leading to economical and effctive utilization of the expensive Pt catalysts. 【Pt毒化限制商业化】

【Pt毒化限制商业化】

[26] C. Zhang, L. Xu, Y. Yan, J. Chen, Controlled synthesis of Pt nanowires with ordered large mesopores for methanol oxidation reaction, Scientific Reports, 2016, 6.

However, intermediate species produced in the process of electro-oxidation  
of methanol can poison the Pt catalysts, which limits the wide spread commercialization of the DMFCs. 【性能依赖于尺寸和形貌，大量工作致力于形貌方面】

【性能依赖于尺寸和形貌，大量工作致力于形貌方面】

[26] C. Zhang, L. Xu, Y. Yan, J. Chen, Controlled synthesis of Pt nanowires with ordered large mesopores for methanol oxidation reaction, Scientific Reports, 2016, 6.

Since the  
activity and stability of the nanostructured Pt materials are highly dependent on their surface structure, particle  
size and morphology, great effrts have been focused on developing various nanostructured Pt materials such as  
Pt nanoparticles4,5, Pt nanowires6,7, Pt nanotubes8,9, Pt nanospheres10,11, and mesoporous Pt12,13 to achieve the Pt  
catalysts with higher activity and better poisoning tolerance. 【纳米线优势】

【纳米线优势】

[26] C. Zhang, L. Xu, Y. Yan, J. Chen, Controlled synthesis of Pt nanowires with ordered large mesopores for methanol oxidation reaction, Scientific Reports, 2016, 6.

Among them, one-dimensional (1D) nanostructured  
Pt materials, such as Pt nanowires6,7 and Pt nanotubes9,14, have received growing attention due to their anisotropic morphology that can improve the mass and electron transport, and the catalyst utilization15. Furthermore,  
compared to 0D Pt nanoparticles, 1D Pt nanostructures have a better durability due to their longitudinal axis  
structures, which make the materials less vulnerable to dissolution and aggregation during the electrocatalytic  
electrode reactions15. 【纳米线缺点，面积小，介孔纳米线】

【纳米线缺点，面积小，介孔纳米线】

[26] C. Zhang, L. Xu, Y. Yan, J. Chen, Controlled synthesis of Pt nanowires with ordered large mesopores for methanol oxidation reaction, Scientific Reports, 2016, 6.

However, 1D nanostructured Pt materials usually have smaller specific surface areas, resulting in inferior electrocatalytic activities to the Pt catalysts. Ordered mesoporous Pt nanowires, a novel type of 1D  
Pt nanomaterials, possess particular advantages of both 1D nanostructure and high surface area. Compared with  
the solid Pt nanowires, mesoporous Pt nanowires with ordered mesopores have larger specifi surface area and  
are more easily accessible for the guest molecules due to their ordered interconnected mesopores16.  
【纳米线通常的制备方法】

【纳米线通常的制备方法】

[26] C. Zhang, L. Xu, Y. Yan, J. Chen, Controlled synthesis of Pt nanowires with ordered large mesopores for methanol oxidation reaction, Scientific Reports, 2016, 6.

Typically, ordered porous metal nanowires can be prepared by a dual templating strategy which either combines a hard-templating (e.g., 1D porous membrane) and a softtemplating (e.g., lyotropic liquid crystal (LLC))  
techniques (referred to as hard/softtemplating method) or employs both hard-templating (e.g., 1D porous

membrane and self-assembled silica or polymer spheres) techniques (referred to as hard/hard-templating  
method). 【双模板法提供了纳米线制备途径，软硬模板，文献】

【双模板法提供了纳米线制备途径，软硬模板，文献】

[26] C. Zhang, L. Xu, Y. Yan, J. Chen, Controlled synthesis of Pt nanowires with ordered large mesopores for methanol oxidation reaction, Scientific Reports, 2016, 6.

The dual templating method provides a satisfactory way to control the pore size and the surface structure of the wires. The diameter of the porous metal wires can be confied by the channels of the porous membrane and the pore structure can be controlled by the mesoporous template (such as LLCs as a sof template17–19,  
or self-assembled spheres as a hard template20–22) priorly deposited in the channels of the porous membrane.  
Compared to the hard/soft templating method, the hard/hard-templating method based on 1D porous membrane and self-assembled nanospheres ( <50 nm) would have great advantage in producing nanoporous metal  
nanowires with controlled large mesopores ( >10 nm), which are important for effient diffsion of guest species during the reactions. Th nanospheres (e.g., silica nanospheres) used to fil in the porous membrane can be  
facilely prepared by the published method23,24 and their easily controlled diameters of 10–50 nm can defie the  
mesopores of the metals25. Also, the long-range order of the mesoporous structures in the fial metal replicas can  
be obtained from the close-packed nanospheres with high thermal stability.  
Li et al. 20 fist reported the preparation of porous metal (Au and Ni) wires with controllable morphology from  
directed assemblies of spheres in 1D porous membranes, but the macroscale of the pores limits their applications.  
Bechelany et al. 22 reported a similar dual templating method to fabricate Co nanowires with controlled porosity.  
【系统研究纳米线没有被报道】

【系统研究纳米线没有被报道】

[26] C. Zhang, L. Xu, Y. Yan, J. Chen, Controlled synthesis of Pt nanowires with ordered large mesopores for methanol oxidation reaction, Scientific Reports, 2016, 6.

However, in the previous reports, the systematic study of the fabrication of metal nanowires with various large mesopores (10–50 nm) and their properties has not been described. 【纳米线电沉积和化学制备方法优劣】

【纳米线电沉积和化学制备方法优劣】

[26] C. Zhang, L. Xu, Y. Yan, J. Chen, Controlled synthesis of Pt nanowires with ordered large mesopores for methanol oxidation reaction, Scientific Reports, 2016, 6.

Furthermore, electrochemical deposition was  
typically used to grow the metals inside the dual templates in these reports. By contrast, chemical reduction deposition offrs a simple and cost-effctive way to replicate the structure of the porous template in the whole thickness range, without the need of using external electric fild sources and electronically conductive substrates26,27.  
【本文，报道了…介孔纳米线的制备方法】

【本文，报道了…介孔纳米线的制备方法】

[26] C. Zhang, L. Xu, Y. Yan, J. Chen, Controlled synthesis of Pt nanowires with ordered large mesopores for methanol oxidation reaction, Scientific Reports, 2016, 6.

In this study, we fist report the chemical reduction fabrication of the mesoporous Pt nanowires with ordered  
large mesopores from AAO membranes with silica nanospheres assembled in the channels. 【本文，电化学性能也被研究】

【本文，电化学性能也被研究】

[26] C. Zhang, L. Xu, Y. Yan, J. Chen, Controlled synthesis of Pt nanowires with ordered large mesopores for methanol oxidation reaction, Scientific Reports, 2016, 6.

Also, the electrocatalytic properties of the mesoporous Pt nanowires for the methanol oxidation reaction (MOR) are investigated.  
【本文，纳米线结构期望提高活性】

【本文，纳米线结构期望提高活性】

[26] C. Zhang, L. Xu, Y. Yan, J. Chen, Controlled synthesis of Pt nanowires with ordered large mesopores for methanol oxidation reaction, Scientific Reports, 2016, 6.

The Pt nanowires with ordered large mesopores would be desirable to improve the electrocatalytic activity due  
to the effient transport of molecules and ions from the interconnected ordered large mesopores for increasing  
accessibility to the active sites, as well as enhance the durability owing to their longitudinal axis structures.【】

## [27] L. Wu, Z. Liu, M. Xu, J. Zhang, X. Yang, Y. Huang, J. Lin, D. Sun, L. Xu, Y. Tang, Facile synthesis of ultrathin Pd-Pt alloy nanowires as highly active and durable catalysts for oxygen reduction reaction, International Journal of Hydrogen Energy, 2016, 41: 6805-6813.

Introduction  
【由于。。。染料电池受到关注】

【由于。。。染料电池受到关注】

[27] L. Wu, Z. Liu, M. Xu, J. Zhang, X. Yang, Y. Huang, J. Lin, D. Sun, L. Xu, Y. Tang, Facile synthesis of ultrathin Pd-Pt alloy nanowires as highly active and durable catalysts for oxygen reduction reaction, International Journal of Hydrogen Energy, 2016, 41: 6805-6813.

As one of the most promising and attractive renewable energy  
sources for the future, proton exchange membrane fuel cells  
(PEMFCs) have drawn tremendous attention owing to their  
high energy conversion efficiency, low operation temperature  
and environmentally benign products [1e5]. 【缓慢的动力学，差的稳定性是商业化的挑战】

【缓慢的动力学，差的稳定性是商业化的挑战】

[27] L. Wu, Z. Liu, M. Xu, J. Zhang, X. Yang, Y. Huang, J. Lin, D. Sun, L. Xu, Y. Tang, Facile synthesis of ultrathin Pd-Pt alloy nanowires as highly active and durable catalysts for oxygen reduction reaction, International Journal of Hydrogen Energy, 2016, 41: 6805-6813.

However, the  
sluggish kinetics and poor electrocatalyst durability of the  
oxygen reduction reaction (ORR) occurred at the cathode  
poses a severe challenge to the large-scale commercialization  
of PEMFCs [6e10]. 【期望探索高活性催化剂，由于pt颗粒的缺点】

【期望探索高活性催化剂，由于pt颗粒的缺点】

[27] L. Wu, Z. Liu, M. Xu, J. Zhang, X. Yang, Y. Huang, J. Lin, D. Sun, L. Xu, Y. Tang, Facile synthesis of ultrathin Pd-Pt alloy nanowires as highly active and durable catalysts for oxygen reduction reaction, International Journal of Hydrogen Energy, 2016, 41: 6805-6813.

In this regard, it is highly desirable to  
explore more active catalysts with superior performance and  
durability than the traditionally employed carbon-supported  
Pt nanoparticles (Pt/C), which greatly suffer from the significant loss of Pt electrochemical surface area (ECSA) over time

due to the corrosion of the carbon support and Pt dissolution/  
aggregation/Oswald ripening during fuel cell operation [11,12].【纳米线优势】

【纳米线优势】

[27] L. Wu, Z. Liu, M. Xu, J. Zhang, X. Yang, Y. Huang, J. Lin, D. Sun, L. Xu, Y. Tang, Facile synthesis of ultrathin Pd-Pt alloy nanowires as highly active and durable catalysts for oxygen reduction reaction, International Journal of Hydrogen Energy, 2016, 41: 6805-6813.

Fortunately, one-dimensional (1D) Pt-based nanostructures,  
such as nanowires and nanotubes, have been demonstrated  
capable of addressing some of the issues of Pt nanoparticles in  
catalyzing ORR, owing to their inherent structural characteristics, i.e., high stability, preferential exposure of highly active  
crystal facets, and easy electron transport [13e18]. Especially,  
ultrathin nanowires with higher surface-to-volume ratios  
could provide more electrocatalytic active sites and thus  
enhanced performances, further improving the utilization  
efficiency of noble metal atoms. 【纳米线制备困难的原因】

【纳米线制备困难的原因】

[27] L. Wu, Z. Liu, M. Xu, J. Zhang, X. Yang, Y. Huang, J. Lin, D. Sun, L. Xu, Y. Tang, Facile synthesis of ultrathin Pd-Pt alloy nanowires as highly active and durable catalysts for oxygen reduction reaction, International Journal of Hydrogen Energy, 2016, 41: 6805-6813.

Nevertheless, anisotropic  
growth of Pt-based nanowires is generally difficult mainly  
because of the fact that Pt itself has an inherent symmetric  
face-centered cubic (fcc) crystal feature [19]. 【纳米线制备方法】

【纳米线制备方法】

[27] L. Wu, Z. Liu, M. Xu, J. Zhang, X. Yang, Y. Huang, J. Lin, D. Sun, L. Xu, Y. Tang, Facile synthesis of ultrathin Pd-Pt alloy nanowires as highly active and durable catalysts for oxygen reduction reaction, International Journal of Hydrogen Energy, 2016, 41: 6805-6813.

To this end, a  
variety of synthetic strategies, such as hard template-engaged  
method [20,21], surfactant/organic ligand-assisted synthesis  
[22e24], phase transfer method [19,25,26], and seed-mediated  
method [27], have been developed for the synthesis of various  
1D Pt-based nanostructures. 【模板、有机添加剂，复杂过程阻碍实际的应用】

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[27] L. Wu, Z. Liu, M. Xu, J. Zhang, X. Yang, Y. Huang, J. Lin, D. Sun, L. Xu, Y. Tang, Facile synthesis of ultrathin Pd-Pt alloy nanowires as highly active and durable catalysts for oxygen reduction reaction, International Journal of Hydrogen Energy, 2016, 41: 6805-6813.

Despite all these remarkable  
achievements, the template-removal, organic solventinvolvement or complicate processes hinders their practical  
applications. 【发展简单的纳米线制备方法仍存在挑战】

【发展简单的纳米线制备方法仍存在挑战】

[27] L. Wu, Z. Liu, M. Xu, J. Zhang, X. Yang, Y. Huang, J. Lin, D. Sun, L. Xu, Y. Tang, Facile synthesis of ultrathin Pd-Pt alloy nanowires as highly active and durable catalysts for oxygen reduction reaction, International Journal of Hydrogen Energy, 2016, 41: 6805-6813.

Therefore, it still remains a great challenge to  
develop simple and reliable synthetic methods, which require  
being environmentally friendly and energy efficient, for the  
fabrication of Pt-based nanowires. 【】  
On the other hand, the electrocatalytic performance of the  
Pt-based nanocatalysts could be significantly improved by  
partially substituting Pt with a secondary metal. The incorporation of a secondary metal could not only decrease the  
consumption of scarce Pt required in electrocatalysis, but also  
modify the electronic structure of Pt, which enables to tune  
the binding energy between Pt and oxygen [28,29]. Particularly, it is well demonstrated that Pd can effectively enhance  
the ORR activity and durability of Pt catalysts owing to the  
“synergistic effect” [30e32]. The performance enhancement is  
believed to originate from the downshift of the d-band center  
of Pt in the alloy structure, which gives rise to a decrease of the  
bonding strength between Pt and the oxygenated species (e.g.,  
OHads) and thus an increased number of available Pt sites for  
oxygen adsorption. Taken together, bimetallic PdePt ultrathin  
nanowires are regarded as a highly promising candidate for  
efficient ORR electrocatalysts.  
 【本文，我们报道了超薄纳米线一步制备方法….】

【本文，我们报道了超薄纳米线一步制备方法….】

[27] L. Wu, Z. Liu, M. Xu, J. Zhang, X. Yang, Y. Huang, J. Lin, D. Sun, L. Xu, Y. Tang, Facile synthesis of ultrathin Pd-Pt alloy nanowires as highly active and durable catalysts for oxygen reduction reaction, International Journal of Hydrogen Energy, 2016, 41: 6805-6813.

Herein, we report an efficient one-pot hydrothermal synthesis of uniform PdePt alloy ultrathin nanowires with a high  
yield as an efficient electrocatalyst for ORR. 【本文，添加剂在。。。起到重要作用，容易去除】

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[27] L. Wu, Z. Liu, M. Xu, J. Zhang, X. Yang, Y. Huang, J. Lin, D. Sun, L. Xu, Y. Tang, Facile synthesis of ultrathin Pd-Pt alloy nanowires as highly active and durable catalysts for oxygen reduction reaction, International Journal of Hydrogen Energy, 2016, 41: 6805-6813.

The elaborate  
introduction of NaI as a structure-directing agent and block  
copolymer Pluronic F127 as a stabilizing agent plays a key role  
in the formation of the ultrathin PdePt nanowires through the  
manipulation of reaction kinetics. Compared with the  
commonly used surfactant, such as PVP or CTAB, nonionic  
copolymer Pluronic F127 is easily removable from the nanoparticle surface, which can effectively avoid blocking and  
poisoning of the active surface sites [33,34]. 【本文，一步水热合成方法优势】

【本文，一步水热合成方法优势】

[27] L. Wu, Z. Liu, M. Xu, J. Zhang, X. Yang, Y. Huang, J. Lin, D. Sun, L. Xu, Y. Tang, Facile synthesis of ultrathin Pd-Pt alloy nanowires as highly active and durable catalysts for oxygen reduction reaction, International Journal of Hydrogen Energy, 2016, 41: 6805-6813.

The synthetic  
strategy outlined here is more promising for practical applications due to its low cost, environmental benign and largescale production capability. 【本文，电化学活性】

【本文，电化学活性】

[27] L. Wu, Z. Liu, M. Xu, J. Zhang, X. Yang, Y. Huang, J. Lin, D. Sun, L. Xu, Y. Tang, Facile synthesis of ultrathin Pd-Pt alloy nanowires as highly active and durable catalysts for oxygen reduction reaction, International Journal of Hydrogen Energy, 2016, 41: 6805-6813.

Significantly, the as-prepared ultrathin PdePt alloy nanowires demonstrate to be an extraordinary and robust ORR catalyst compared with commercial Pd  
black and Pt black catalysts. The electronic effect along with  
the ultrathin one-dimensional structure accounts for the  
excellent ORR performance.【】

## [28] M. E. Scofield, Y. Zhou, S. Yue, L. Wang, D. Su, X. Tong, M. B. Vukmirovic, R. R. Adzic, S. S. Wong, Role of chemical composition in the enhanced catalytic activity of Pt-based alloyed ultrathin nanowires for the hydrogen oxidation reaction under alkaline conditions, ACS Catalysis, 2016, 6: 3895-3908.

1. INTRODUCTION  
【碱性燃料电池受到关注】

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[28] M. E. Scofield, Y. Zhou, S. Yue, L. Wang, D. Su, X. Tong, M. B. Vukmirovic, R. R. Adzic, S. S. Wong, Role of chemical composition in the enhanced catalytic activity of Pt-based alloyed ultrathin nanowires for the hydrogen oxidation reaction under alkaline conditions, ACS Catalysis, 2016, 6: 3895-3908.

With the increased interest in the development of hydrogen  
fuel cells as a plausible alternative to internal combustion  
engines, recent work has focused on creating viable alkaline fuel  
cells (AFC), which employ an alkaline medium as opposed to  
acid as the primary electrolyte. 【碱性介质有利于碱性燃料电池】

【碱性介质有利于碱性燃料电池】

[28] M. E. Scofield, Y. Zhou, S. Yue, L. Wang, D. Su, X. Tong, M. B. Vukmirovic, R. R. Adzic, S. S. Wong, Role of chemical composition in the enhanced catalytic activity of Pt-based alloyed ultrathin nanowires for the hydrogen oxidation reaction under alkaline conditions, ACS Catalysis, 2016, 6: 3895-3908.

In effect, AFCs possess a  
number of important benefits associated with the presence of a  
more favorable and desirable alkaline electrolyte medium.  
【】Specifically, these include (i) the ability to use non-preciousmetal catalysts due to their increased stability, (ii) a diminished  
degree of degradation and corrosion of Pt-based catalysts, and  
(iii) a general reduction in the amount of deterioration inherent  
to the overall fuel cell configuration.1 −3  
Additionally, the reaction that occurs at the cathode, namely  
the oxygen reduction reaction (ORR), tends to possess faster  
kinetics in alkaline media.1,4 However, there remains a  
significant need for improvement at the anode side of the  
fuel cell where the oxidation of hydrogen occurs, because  
unfortunately, the kinetics for this reaction process are  
inherently slower in alkaline media versus those in acid  
electrolytes. 【Pt高效，然而酸性中动力学缓慢，易毒化】

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[28] M. E. Scofield, Y. Zhou, S. Yue, L. Wang, D. Su, X. Tong, M. B. Vukmirovic, R. R. Adzic, S. S. Wong, Role of chemical composition in the enhanced catalytic activity of Pt-based alloyed ultrathin nanowires for the hydrogen oxidation reaction under alkaline conditions, ACS Catalysis, 2016, 6: 3895-3908.

In particular, despite the fact that platinum is  
known to be the most active metal for initiating the hydrogen  
oxidation reaction (HOR) in alkaline media, it unfortunately  
still exhibits 2 orders of magnitude slower kinetics than those  
measured in corresponding acid electrolytes.2,3 Moreover,  
existing catalysts are particularly susceptible to CO poisoning.【】  
Therefore, to deal with all of these issues, there is a tangible  
need to create unconventional geometries possessing superior  
HOR kinetics in alkaline media whose performance inherently  
surpasses that of elemental, monometallic Pt.

One strategy is by generating alternative architectures: i.e.,  
structures that incorporate monometallic nanomaterials as  
constituent components of a larger whole. Such an approach  
encompasses efforts to generate new and interesting classes of  
hierarchical architectures such as alloy and core − shell motifs,  
wherein the local electronic environment of Pt, for example,  
can be systematically altered through corresponding variations  
in structure and composition.  
However, the rationale for the expected improvement in  
both activity and kinetics with these novel materials in alkaline  
media is still a matter of controversy. In effect, contradictory  
theories have been proposed to explain enhancements observed  
with alloyed structures in particular. Some have suggested that  
the enhanced activity of these catalysts originates from the  
increased oxophilicity of the alloyed metal. In particular,  
Markovic and co-workers5 have theoretically proposed that  
OH ad is a key reactant species in the HOR and that the  
presence of a more oxophilic metal should improve the reaction  
kinetics and activity of Pt. A different group6 experimentally  
tested this hypothesis by investigating the electrochemical  
activity of commercial PtRu and of Pt nanoparticles supported  
onto carbon (NP/C) control samples. Ultimately, this group  
discovered that PtRu NP/C achieved higher activities than Pt  
NP/C but ascribed the enhancement to an optimized hydrogen  
binding energy (HBE), which was attributed to an electronic  
effect imparted onto Pt by Ru as opposed to an oxophilic effect.  
Their rationale rested on the observation that PtRu NP/C did  
not possess a lower onset potential for CO desorption by  
comparison with Pt NP/C, which would have yielded  
incontrovertible evidence for the presence of an oxophilic  
effect.  
 【本文，系统研究配体和晶格应变机理问题。。。】

【本文，系统研究配体和晶格应变机理问题。。。】

[28] M. E. Scofield, Y. Zhou, S. Yue, L. Wang, D. Su, X. Tong, M. B. Vukmirovic, R. R. Adzic, S. S. Wong, Role of chemical composition in the enhanced catalytic activity of Pt-based alloyed ultrathin nanowires for the hydrogen oxidation reaction under alkaline conditions, ACS Catalysis, 2016, 6: 3895-3908.

In this light, in this study herein, we aim to more  
systematically address this key mechanistic question by  
synthesizing Pt-based metallic alloys wherein we take the  
advantage of the combination of both a “ligand effect” and a  
“lattice strain effect”. 【】By the “ligand effect”,7 −9 we refer to a  
phenomenon in which the electronic properties of the active  
sites of one transition metal are modified by the introduction of  
another metal. Specifically, it should manifest itself in the  
corresponding adjustment of the metal −adsorbed hydrogen  
(i.e., M −Had) interaction, which we believe to be the rate determining step for the HOR.6 That is, our PtM nanowires  
(NWs) (wherein M = a plentiful transition metal) should  
evince enhanced HOR kinetics, as H should be bound less  
strongly onto alloyed surfaces. Furthermore, by the term  
“lattice strain effect”, we refer to changes in the surface Pt −Pt  
bond distance as a result of the incorporation of other  
transition metals, thereby leading to changes in the d band  
center of Pt.10 −13 Throughout this paper, we use the term  
“electronic effects” to embody, encompass, and incorporate the  
synergistic association of both ligand and lattice strain effects.  
Indeed, Pt-based alloyed systems have previously been  
investigated by computational analysis, and it has been  
postulated that the structural and electronic interactions  
between the two alloyed metals should promote more facile  
HOR kinetics due to changes in the “effective” hydrogen  
binding energy (HBE).14,15 Previous theoretical work performed by Nørskov and co-workers16 calculated the HBEs for  
various individual metals, and they found that a number of  
them possessed HBEs that were very favorable for hydrogen  
oxidation. Specifically, this work15 also suggested that the  
incorporation of certain metals such as Ni, Co, Fe, Cu, and Ru  
into Pt-containing alloys represents a viable option for  
achieving hydrogen binding with an “optimal” HBE: i.e., a  
value closer to 0 by comparison with Pt bulk itself. Additional  
work performed by Wang and co-workers17 implied that by  
alloying Pt with a metal possessing a comparatively stronger  
hydrogen binding energy, one could conceivably shift the  
overall HBE to more favorable values: i.e., to weaker HBE  
values by comparison with that of pure Pt itself.  
For optimal HOR performance, we ultimately seek a  
weakening in the hydrogen binding energy by comparison  
with that of Pt, an assertion supported by others.17 In effect,  
there is a strengthening of the HBE as the d band center moves  
closer to the Fermi level of a metal such as Pt.10,18 Our goal is  
the opposite, and therefore, our objective has been to create  
alloyed nanomaterials that demonstrate a weakening in HBE by  
moving the d band center away from the Pt Fermi level.  
Hence, on the basis of previous HBE calculations associated  
with various transition metals,16,19 we can potentially tailor  
novel electrocatalysts with improved HOR kinetics by  
deliberatively and systematically altering the alloy composition  
and, therefore, control the corresponding variations in HBE.  
Therefore, our goal has been to correlate composition with  
activity. Additionally, our objective of replacing expensive noble  
metals with cheaper, more abundant metals is essential for  
designing electrocatalysts for mass production.  
Apart from rationally varying the chemical compositions of  
our Pt-based alloy structures, we have also tailored the  
morphology of our catalysts. 【纳米线优势，纳米线各向异性提高性能原因】

【纳米线优势，纳米线各向异性提高性能原因】

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In effect, crystalline one dimensional (1D) catalysts have previously been shown to  
possess high aspect ratios, fewer potentially deleterious defect  
sites, and short segments of crystalline planes, all of which  
contribute to the enhanced activity of 1D systems as compared  
with their zero-dimensional (0D) counterparts.20 −22 Furthermore, as per our recent Perspective article on this issue,23a  
anisotropic nanostructures such as Pt NWs maintain a favorable  
downshift in the Pt d band, which contributes to a weaker  
d −π\* interaction with the adsorbed CO, thereby improving  
Pt’s ability to oxidize adsorbed CO at potentials closer to the  
thermodynamic potential for the methanol oxidation reaction  
(MOR). 【纳米线可以显示不同晶面结构】

【纳米线可以显示不同晶面结构】

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Moreover, the surfaces of 1D morphologies can be  
tuned so as to preferentially display different crystal facets.8,21  
 【纳米线优势，和商业ptC对比】

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In addition, the rates of dissolution and ripening processes have  
been demonstrated to be significantly slower in the case of 1D  
nanostructures, by comparison with those of commercial Pt  
NP/C. 【】All of these findings suggest that 1D architectures  
represent promising motifs for HOR catalysts.  
【降低纳米线直径】

【降低纳米线直径】

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Our last novel variation for HOR has been to reduce the  
average diameters of our 1D nanowires tested to the ultrathin  
size regime (<5 nm). In doing so, we should be able not only to  
decrease the amount of defect sites present in the wire, which  
has been previously shown to favorably alter the surface energy  
of Pt, but also to minimize any lattice boundary defects. Indeed,  
the presence of defects contributes to the degradation of Pt,  
since lower coordination Pt surface sites are more prone to  
irreversible oxidation.21  
【本文，将不仅证明。。的理论结果，还将研究配位体、晶格应变效应】

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Overall, in this study, we not only intend to verify the  
theoretical results proposed by Mavrikakis and co-workers15 by  
experimentally synthesizing a series of ultrathin 1D Pt-based  
binary alloys with controllable composition and subsequently  
testing their HOR activities within an alkaline electrolyte but  
also propose to investigate the combined roles of the “ligand  
effect” and the “lattice strain effect” in governing HOR activity.  
【本文，报道了系统的构效关联性】

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[28] M. E. Scofield, Y. Zhou, S. Yue, L. Wang, D. Su, X. Tong, M. B. Vukmirovic, R. R. Adzic, S. S. Wong, Role of chemical composition in the enhanced catalytic activity of Pt-based alloyed ultrathin nanowires for the hydrogen oxidation reaction under alkaline conditions, ACS Catalysis, 2016, 6: 3895-3908.

Our work represents the the first systematic correlation of HOR  
activity with key structural parameters that notably influence

surface chemistry and the presence of active sites for a variety of  
binary alloy nanowire systems, operating in alkaline media.【本文，活性通过结合形貌，尺寸，化学成分提高】

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Our  
overall results highlight that our intrinsic activities can be  
deliberatively improved up on and optimized through a  
j u d i c i o u s c o m b i n a t i o n o f ( i ) m o r p h o l o g y , ( i i ) c h e m i c a l  
composition, and (iii) size. 【本文，电化学活性】

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Specifically, we have observed that  
excellent HOR activity values, whose trend approximates that  
o f p r e v i o u s t h e o r e t i c a l p r e d i c t i o n s ,15 can be specifically  
achieved with 1D anisotropic motifs, characterized by both  
<5 nm diameters and well-chosen Pt-based alloyed compositions.【】  
To create our test materials, we have employed an ambient  
and facile wet synthesis method,24,25 which we have previously  
applied to the generation of ultrathin ternary PtRuFe nanowire  
systems,23b in order to produce ultrathin Pt-based binary alloy  
NW systems. This protocol involves the reduction of metal  
precursors with sodium borohydride in the presence of a socalled “soft template”, created by cetyltrimethylammonium  
bromide (CTAB) surfactant within a two-phase water −  
chloroform system. One of the advantages of this technique  
is that the wire dimensionality is fundamentally controlled by  
the size and shape of the “soft template” pores, and hence, it is  
rather straightforward to create porous, high-surface-area  
networks consisting of interconnected, “wormlike” metallic  
nanowires, possessing average diameters of as little as 1.9 nm.  
In terms of desirable chemical compositions, it has been  
reported that the presence of 30% Ru dopant, as in the Pt7Ru3  
system, yielded exceptionally high activities.26 −28 As such, we  
used this particular binary alloy composition as our explicit  
“starting point” from which to generate possible permutations  
for other Pt-based alloys, so as to create a family of effective  
electrochemically active catalysts.

## [29] S. Lu, K. Eid, M. Lin, L. Wang, H. Wang, H. Gu, Hydrogen gas-assisted synthesis of worm-like PtMo wavy nanowires as efficient catalysts for the methanol oxidation reaction, Journal of Materials Chemistry A, 2016, 4: 10508-10513.

Introduction  
【燃料电池有前景】

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[29] S. Lu, K. Eid, M. Lin, L. Wang, H. Wang, H. Gu, Hydrogen gas-assisted synthesis of worm-like PtMo wavy nanowires as efficient catalysts for the methanol oxidation reaction, Journal of Materials Chemistry A, 2016, 4: 10508-10513.

Direct methanol fuel cells (DMFCs) are among the most  
promising electrochemical energy conversion devices due to  
their high power density, ease of handling, low environmental  
impact, and low operating temperature. 【Pt成本，不稳定，易毒化等限制其商业化】

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However, DMFC commercialization is hindered by the high cost, low-abundance, and instability of the Pt catalyst that is easily poisoned by  
intermediate species such as CO or CHO. 1– 3 【大量研究致力于尺寸，形貌和成分，晶面的可控，文献】

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Numerous efforts  
are dedicated to overcome these drawbacks, culminating in  
controlling the size, morphology, surface-facets, and composition of Pt NCs. 4–14 For instance, the anisotropic structures of  
Pt NCs, such as nanocube,4 nanowire,5 and nanodendritic  
structures,6 exhibit superior catalytic activity compared to their  
spherical or solid counterparts.  
【纳米线优势】

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Worm-like wavy nanowires are among the most active  
nanostructures, due to their inherent defects, high accessible  
surface area, and multiple corners, which are favorable features  
for enhancing the catalytic activity and durability of Pt NCs.7–10 【纳米线制备方法，基于导向吸附机制】

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Thereby, various worm-like nanowires of Pt, Pd, Au, CoPt, and  
FePt were synthesized by polyol, thermal decomposition, and  
seed-mediated growth methods based on the oriented attachment mechanism.11–17 For instance, worm-like nanowires of  
Pt53Ag47 were synthesized by reduction of metal precursors in  
the presence of oleic acid, oleylamine, 1,2-hexadecanediol, and  
diphenyl ether at 200 C.7 【】As depicted by the previous papers, in  
addition to worm-like structures, controlling the composition of  
Pt NCs via alloying with less noble metals such as Co, Cu, Ni,  
and Ru can further enhance their catalytic activity and durability.18–27 This is due to the fact that alloying and strain effects  
facilitate adsorption of methanol molecules and retard  
adsorption of reaction intermediates.19–21 【纳米线简单合成方法是一个大的挑战】

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[29] S. Lu, K. Eid, M. Lin, L. Wang, H. Wang, H. Gu, Hydrogen gas-assisted synthesis of worm-like PtMo wavy nanowires as efficient catalysts for the methanol oxidation reaction, Journal of Materials Chemistry A, 2016, 4: 10508-10513.

Therefore, the development of a facile synthesis method for controlled fabrication  
of Pt-based worm-like nanowires with enhanced activity and  
durability is a grand challenge.【】  
Mo is among the most promising underlying transition  
metals that can be used to incorporate into Pt-based NCs due  
to its high poisoning tolerance towards the MOR at low

temperature. This is ascribed to the bi-functional mechanism  
and electronic effect which ease the cleavage of C–H at lower  
potentials and concurrently weaken the binding energy of  
Pt–CO by an oxygen spillover effect during the methanol

oxidation. 22 Various groups reported the substantial effect of  
Mo and Mo oxides on the improvement of the MOR activity and  
durability of Pt compared to commercial Pt/C. 23 For example,  
Manthiram et al. investigated the effect of Mo on the electrocatalytic performance of Pt–Sn–Mo/C. 24 The conventional polyol  
method was used and the incorporation of Mo enhanced the  
catalytic activity. However, active site agglomeration therein  
may be a problem.  
【本文，提供了一步法制备纳米线，不易于团聚】

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[29] S. Lu, K. Eid, M. Lin, L. Wang, H. Wang, H. Gu, Hydrogen gas-assisted synthesis of worm-like PtMo wavy nanowires as efficient catalysts for the methanol oxidation reaction, Journal of Materials Chemistry A, 2016, 4: 10508-10513.

Inspired by this, we provide a facile one-pot method for  
controlled synthesis of worm-like PtMo wavy nanowires. The  
study of PtMo wavy nanowires is very limited and in this paper  
we achieved it by mixing metal precursors in OAm at 100 C  
followed by heating to 165 C in an autoclave under H2. The asprepared worm-like PtMo wavy nanowires are self-supported  
interconnected network structures, which are not susceptible to  
active site agglomeration. 【本文，电化学性能】

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They depicted a higher catalytic  
activity and durability compared with PtMo nanodendrites, Pt  
nanocubes, and Pt/C towards the MOR. 【本文，合成机制开启了新的前沿】

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The synthetic mechanism was explained by a combination between the autocatalytic  
effect and oriented attachment growth and this proposed  
method is different from multistep traditional methods in its  
simplicity, which may open a new frontier for the fabrication of  
multi-metallic Pt-based NCs for various electrocatalytic  
applications.【】

## [30] M. Liu, S. He, W. Chen, Free-Standing 3D Hierarchical Carbon Foam-Supported PtCo Nanowires with "pt Skin" as Advanced Electrocatalysts, Electrochimica Acta, 2016, 199: 218-226.

1. Introduction  
【由于。。。液态燃料电池发展迅速】

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In the past decades, liquid fuel cells (FCs) have been developed quickly as a type of clean energy source with the advantages of high energy density, ease of storage and transport of liquid fuels, no limit by Carnot cycle laws, low operating pressure and temperature.[1, 2] 【】Among the developed fuel cells, alkaline fuel  
cells (AFCs) provide a less corrosive environment for catalysts and electrodes[3] and offer an alternative  
solution to the low-temperature proton exchange membrane fuel cells (PEMFCs).[4] In a typical fuel cell,  
chemical fuels－ small organic molecules, such as hydrogen, formic acid, methanol or ethanol are oxidized  
at anode, while oxygen is reduced at cathode. 【缓慢动力学对燃料电池性能有重要作用】

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Compared to the anodic fuel oxidation, the sluggish oxygen  
reduction reaction (ORR) on cathode shows more effect on the overall fuel cell performance. 【Pt缺点】

【Pt缺点】

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Although Pt nanocrystals shows the best catalytic activity for ORR, its obvious shortcomings, such as high cost, heavy CO species poisoning, slow reaction kinetics and the easy aggregation and dissolution of particles,  
especially in alkaline electrolytes largely limit its practical application in fuel cells. [1, 5] 【高效催化剂设计和制备仍存在挑战，因此制备可控形貌】

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Hence, the design and fabrication of greatly active ORR catalysts with low cost and high durability is still a significant  
challenge.[6, 7] To this end, various Pt-based or low-Pt alloy electrocatalysts with controlled morphology,  
compositions have been fabricated as high performance electrocatalysts for ORR.[8-14] 【】  
As displayed in previous studies, Pt-M (M= Ni, Co, Fe, etc.) alloys present increased number of surface  
d-vacancy, which can assist electron donation from O2 to surface Pt and then result in strong interactions  
between O2 and Pt. The enhancement of O2 adsorption on surface Pt and the waning of the O-O bond result  
in fast scission of the O-O bond and the subsequently enhanced O2 reduction performance.[15-17] 【纳米线优势，文献】

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To date,  
most Pt-M nanocatalysts are based on zero-dimensional nanocrystals. Actually, 1-dimensional  
nanostructures have promising properties as electrocatalysts with large surface area, high catalytic activity  
and stability.[18-23] For instance, Liu et al. synthesized porous Co-rich Pt1Co99 alloy nanowires by  
electrodepositing PtCo alloy into anodic aluminum oxide (AAO) membranes with a following dealloying  
process in a mild medium of 10 wt % H3PO4. Compared to the commercial Pt/C and PtCo/C catalysts, the  
nanoporous Pt1Co99 alloy nanowires exhibited enhanced electrocatalytic activity for methanol oxidation  
reaction (MOR) and showed considerable potential in direct methanol fuel cells (DMFCs) as efficient  
anodic electrocatalysts.[24] Lately, more studies clearly showed that lengthened Pt-based nanostructures  
have higher resistance to dissolution, aggregation, and Ostwald ripening than Pt NPs, and their activity and  
durability for catalyzing the ORR can be enhanced.[20, 22-24] 【减少使用量，降低成本，过渡金属被用作基体】

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Meanwhile, to reduce the dosage of Pt and  
further lower the cost, transition metal nanowires (NWs) can serve as substrates to grow Pt-based  
nanostructures.【】 Based on these previous studies, we designed here Co-templated Pt nanowires to enhance  
the electrocatalytic performance and durability for ORR.  
【为提高分散性，和稳定性，使用了导电基体】

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To improve the dispersion and stability of nanocatalysts, conductive substrates are usually used as  
catalyst supports. Among the used supports, two- and three-dimensional carbon structures have attracted increasing attention. In recent years, there have been a lot of research focusing on three-dimensional  
graphene foam-supported metal catalysts, such as Pt[25], Fe3O4[26], FexN[27], CoO[28], and their  
applications in fuel cells[5], sensors[28], supercapacitors[29] and solar cells[30] etc. Meanwhile, a kind of  
novel free-standing 3D carbon foam (CF) has aroused considerable interest as catalyst supporting material  
owing to their easy availability, outstanding mechanical strength, ultralarge surface area, and excellent  
electrical properties. [31, 32].  
 【本文，我们首次制备了。。。纳米线】

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Here, for the first time PtCo nanowires are in situ grown on 3D carbon foam (PtCo-NWs/CF) and the  
hybrid materials can be used as both fuel cell anodic and cathodic catalysts. 【本文，3d材料的优势】

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Such 3D materials have the  
following advantages as electrocatalysts. First, the tight coupling and strong interaction between the in situ  
produced PtCo nanowire and 3D carbon support can effectively prevent the dissolution, aggregation, and  
Ostwald ripening of NWs, which could effectively improve the stability of NW catalysts than the  
unsupported nanocrystals stored in liquid solvent. Second, the 3D macroporous structure of carbon foam  
and the open space between PtCo nanowires is beneficial for the immersion and diffusion of electrolyte to  
the inside of the electrocatalyst and thus increases the utilization efficiency of PtCo-NW.[32-35]  
Meanwhile, the porous structure of the synthesized 3D structure can enhance the electron transfer and  
mass transport during the electrocatalysis. Third, the synergy effect of Pt and Co in PtCo nanowires can  
enhance the electrocatalytic performance. Finally, “Pt skin” is produced by a simple electrochemical  
treatment in an acidic environment, which leads to the formation of Pt-rich-surface of PtCo nanowires.11,【本文，虽然pt用量少，但是。。纳米线显示了高活性】

【本文，虽然pt用量少，但是。。纳米线显示了高活性】

[30] M. Liu, S. He, W. Chen, Free-Standing 3D Hierarchical Carbon Foam-Supported PtCo Nanowires with "pt Skin" as Advanced Electrocatalysts, Electrochimica Acta, 2016, 199: 218-226.

36, 37] Therefore, although only a small amount of Pt precursor was used, the PtCo nanowires with “Pt  
skin” exhibited high electrocatalytic activity for ethanol oxidation and oxygen reduction 【】

## [31] K. Lin, Y. Lu, S. Du, X. Li, H. Dong, The effect of active screen plasma treatment conditions on the growth and performance of Pt nanowire catalyst layer in DMFCs, International Journal of Hydrogen Energy, 2016, 41: 7622-7630.

Introduction  
【催化剂对燃料电池至关重要】

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[31] K. Lin, Y. Lu, S. Du, X. Li, H. Dong, The effect of active screen plasma treatment conditions on the growth and performance of Pt nanowire catalyst layer in DMFCs, International Journal of Hydrogen Energy, 2016, 41: 7622-7630.

Catalyst layers are crucial components in direct methanol  
fuel cells (DMFCs), where electrochemical reactions take  
place. 【pt的缺点】

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[31] K. Lin, Y. Lu, S. Du, X. Li, H. Dong, The effect of active screen plasma treatment conditions on the growth and performance of Pt nanowire catalyst layer in DMFCs, International Journal of Hydrogen Energy, 2016, 41: 7622-7630.

Platinum is a commonly used catalyst in DMFCs;  
however, the extremely high cost of platinum is a major  
barrier to the commercialisation of DMFCs with platinum as  
the catalyst.【大量研究致力于合金和非贵金属】

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[31] K. Lin, Y. Lu, S. Du, X. Li, H. Dong, The effect of active screen plasma treatment conditions on the growth and performance of Pt nanowire catalyst layer in DMFCs, International Journal of Hydrogen Energy, 2016, 41: 7622-7630.

Great effort has been made during the past  
decades to develop platinum-base alloys [1e9] or nonprecious metal catalysts [10e13] to replace expensive platinum.【Pt高效催化剂】

【Pt高效催化剂】

[31] K. Lin, Y. Lu, S. Du, X. Li, H. Dong, The effect of active screen plasma treatment conditions on the growth and performance of Pt nanowire catalyst layer in DMFCs, International Journal of Hydrogen Energy, 2016, 41: 7622-7630.

Those newly developed catalysts could reduce the cost  
to some extent. However, from activity, selectivity, stability  
and poisoning resistance points of view, pure Pt is still the  
best catalyst for DMFCs [14].  
 【面积是活性的衡量指标之一，期望减少用量，增大面积】

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It is well known that the effective electrochemical surface  
area (ECSA) of catalysts in DMFC electrodes is an important  
measure for their catalytic performance. Hence, it is expected

that enlarging the ECSA value of Pt catalysts would be a  
promising method to reduce the usage of Pt and thus lower its  
cost. 【相对于块状，纳米材料被广泛研究，由于大的活性面积】

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To this end, nano-structured materials have been  
extensively investigated for catalytic application due to their  
larger specific area compared to bulk materials, and some  
improvements have been achieved in the past decade [15e19].【纳米材料形貌可控制备方法】

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[31] K. Lin, Y. Lu, S. Du, X. Li, H. Dong, The effect of active screen plasma treatment conditions on the growth and performance of Pt nanowire catalyst layer in DMFCs, International Journal of Hydrogen Energy, 2016, 41: 7622-7630.

In traditional methods Pt nanoparticles are produced by  
reducing a Pt salt in a aqueous solution by bubbling  
hydrogen [20], ethylene glycol [21] or sodium borohydride  
[22]. These approaches have been further developed in  
recent years for the controlled synthesis of Pt nanostructures with various morphologies. 【纳米线优势，文献】

【纳米线优势，文献】

[31] K. Lin, Y. Lu, S. Du, X. Li, H. Dong, The effect of active screen plasma treatment conditions on the growth and performance of Pt nanowire catalyst layer in DMFCs, International Journal of Hydrogen Energy, 2016, 41: 7622-7630.

Compared to 0-dimensional nanoparticles, 1-dimensional nanostructures,  
like nanotubes and nanowires, exhibit even higher catalytic  
activities, because of their anisotropy and unique structure  
[23]. Du et al. [24] reported a simple and effective method to  
grow nanostructured Pt on gas diffusion layer (GDL) surfaces. Detailed SEM and TEM observations revealed that  
these nanostructured Pt is in the form of nano-wires with a  
typical length of 50-200 nm and a small diameter of  
2.5-3.0 nm. Differing from conventional multi-step process,  
the formation of the Pt nanowires is based on the reduction  
reaction of chloroplatinic acid with formic acid in an  
aqueous solution at room temperature, without using any  
templates or inducing catalysts. Hence, this is an in-situ  
growth method since the Pt nano-wires are formed directly  
on the GDL surfaces by self-assembling. The Pt nanowires  
deposited GDLs exhibit a better catalytic activity and higher  
power density comparing with the commercial Pt nanoparticle coated electrodes. 【】Enhanced performance of Pt  
nanowires in-situ grown on polymer electrode membrane  
using a similar method was also reported [18].  
The preparation of Pt nanowires by the in-situ growth  
approach is conducted in an aqueous environment, and therefore the growth of Pt nanowires is largely influenced by the  
wettability of the substrate, i.e. GDL [25,26] or membrane [27,28].  
Unfortunately, the surface of GDLs or membranes is normally  
hydrophobically treated by coating it with a super hydrophobic  
polymer film (usually PTFE), in order to prevent water flooding  
and facilitate the gas permeation in fuel cell operation [29]. The  
hydrophobicity property greatly retards the growth of Pt nanowires on the substrate surface, resulting in severe aggregation  
and un-uniform growth, and consequently lowers the potential  
catalysis performance of the coated Pt. Hence, surface modificationis urgently needed to enhance the wettability of the super  
hydrophobic GDL surface.  
Some researchers demonstrated the improved wettability  
of polymers using plasma treatments [30e33]. Recently, an  
advanced active screen plasma treatment technology has  
been developed and successfully employed to improve the  
wettability of different types of biopolymers including polyurethane [34] and polycaprolactone [35].  
【本文，新的方法被用于支撑Pt纳米线，具有高活性】

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In our previous feasibility study [36], the newly developed  
active screen plasma (ASP) technique showed the ability to  
improve the growth of Pt nanowire arrays on GDL substrates  
and thus enhance the catalytic performance.【本文，系统研究了。。。对pt纳米线的影响】

【本文，系统研究了。。。对pt纳米线的影响】

[31] K. Lin, Y. Lu, S. Du, X. Li, H. Dong, The effect of active screen plasma treatment conditions on the growth and performance of Pt nanowire catalyst layer in DMFCs, International Journal of Hydrogen Energy, 2016, 41: 7622-7630.

In this work,  
systematic studies were conducted to investigate the influence  
of ASP treatment parameters, namely treatment duration and  
temperature, on the post growth of Pt nanowires on the GDL  
surface as direct cathode gas diffusion electrodes (GDEs) for  
DMFCs in order to identify the optimal treatment conditions 【】

## [32] Y. Liao, G. Yu, Y. Zhang, T. Guo, F. Chang, C. J. Zhong, Composition-tunable PtCu alloy nanowires and electrocatalytic synergy for methanol oxidation reaction, Journal of Physical Chemistry C, 2016, 120: 10476-10484.

■ INTRODUCTION  
【可再生能源】

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[32] Y. Liao, G. Yu, Y. Zhang, T. Guo, F. Chang, C. J. Zhong, Composition-tunable PtCu alloy nanowires and electrocatalytic synergy for methanol oxidation reaction, Journal of Physical Chemistry C, 2016, 120: 10476-10484.

Developing renewable energy technologies to reduce our  
reliance on fossil fuels is one of the biggest challenges for twenty-first century. 【由于。。。燃料电池广受关注】

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[32] Y. Liao, G. Yu, Y. Zhang, T. Guo, F. Chang, C. J. Zhong, Composition-tunable PtCu alloy nanowires and electrocatalytic synergy for methanol oxidation reaction, Journal of Physical Chemistry C, 2016, 120: 10476-10484.

The low emission, high energy conversion efficiency, and ease of storage of many emerging technologies,1 such as proton exchange membrane fuel cells (PEMFCs) and direct methanol fuel cells (DMFCs), hold great potential as a clean energy source and have attracted continuous attention over the past decade. 2【Pt高效催化剂】

【Pt高效催化剂】

[32] Y. Liao, G. Yu, Y. Zhang, T. Guo, F. Chang, C. J. Zhong, Composition-tunable PtCu alloy nanowires and electrocatalytic synergy for methanol oxidation reaction, Journal of Physical Chemistry C, 2016, 120: 10476-10484.

To enable fuel cell technologies, Pt catalysts are the most conventional electrocatalysts.3 −7  
 【pt缺点，及解决方法】

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[32] Y. Liao, G. Yu, Y. Zhang, T. Guo, F. Chang, C. J. Zhong, Composition-tunable PtCu alloy nanowires and electrocatalytic synergy for methanol oxidation reaction, Journal of Physical Chemistry C, 2016, 120: 10476-10484.

However, a critical problem for Pt catalysts is the sky-rocketing  
price due to limited supply. Moreover, the Pt-based anodes are  
vulnerable to be poisoned by a carbonaceous intermediates  
(e.g., CO), which are usually formed during methanol  
oxidation.8,9  
To address the low durability and high scarcity of Pt  
catalysts, one area of extensive research involves loading small size Pt nanoparticles (NPs) on supports such as C,10 NbC,11  
and B  
4C12 which reduce the Pt quantity while obtain a high  
electrochemical activity. 【】Another area of current research  
interests involves developing multimetallic structures that  
combine Pt with a second or third low-cost 3d transition  
metal (e.g., Cu, Fe, Ni, Co, and so forth).13 −16 For example,  
Niu and co-workers prepared PtNi bimetallic nanobundles  
(NBs) by a seed-based diffusion method. For methanol  
oxidation, the PtNi NBs showed an increased catalytic activity  
than that of conventional Pt nanoparticles (NPs).17 Among  
different bimetallic catalysts for methanol oxidation reaction  
(MOR), PtCu catalysts are increasingly attractive due to its  
lower cost, improved catalytic activity,18 and high antipoisoning  
ability.19 There have been a number of reports about catalytic  
performance of PtCu nanocrystals with different shapes for  
MOR, including, for example, PtCu hollow nanocrystals,20  
dendritic PtCu nanocrystals,21 and PtCu nanocubes.22,23 【对于纳米颗粒的缺点，纳米线可以解决】

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In  
contrast to the studies of Pt and PtCu nanoparticle catalysts,  
one-dimensional (1D) nanowires (NWs) exhibit unique  
properties. Some of the potential problems for Pt-based  
nanoparticles include aggregation, Ostwald ripening,24,25  
limited mass transfer, and support corrosion,26 which may be  
overcome by the 1D nanowire structure or its self-supporting  
character. 【】While there are reports on the synthesis of PtPdCu27  
and PtCu  
3  
28  
wavy NWs by coreduction methods, their  
morphologies feature largely interconnected nanoparticle  
chains.29 【本文，很少洞察其催化机理】

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[32] Y. Liao, G. Yu, Y. Zhang, T. Guo, F. Chang, C. J. Zhong, Composition-tunable PtCu alloy nanowires and electrocatalytic synergy for methanol oxidation reaction, Journal of Physical Chemistry C, 2016, 120: 10476-10484.

Little insight into the catalytic mechanism has been  
offered. 【本文，我们报道了一步法制备纳米线】

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[32] Y. Liao, G. Yu, Y. Zhang, T. Guo, F. Chang, C. J. Zhong, Composition-tunable PtCu alloy nanowires and electrocatalytic synergy for methanol oxidation reaction, Journal of Physical Chemistry C, 2016, 120: 10476-10484.

In this paper, we report ultrathin and composition tunable PtCu NWs synthesized by an effective one-pot solvothermal method and the synergistic electrocatalytic properties for MOR. 【】

## [33] L. Li, H. Liu, L. Wang, S. Yue, X. Tong, T. Zaliznyak, G. T. Taylor, S. S. Wong, Chemical Strategies for Enhancing Activity and Charge Transfer in Ultrathin Pt Nanowires Immobilized onto Nanotube Supports for the Oxygen Reduction Reaction, ACS Applied Materials and Interfaces, 2016, 8: 34280-34294.

1. INTRODUCTION  
【可再生能源受到关注】

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[33] L. Li, H. Liu, L. Wang, S. Yue, X. Tong, T. Zaliznyak, G. T. Taylor, S. S. Wong, Chemical Strategies for Enhancing Activity and Charge Transfer in Ultrathin Pt Nanowires Immobilized onto Nanotube Supports for the Oxygen Reduction Reaction, ACS Applied Materials and Interfaces, 2016, 8: 34280-34294.

A growing demand for efficient, low-cost renewable energy has  
sparked great interest in the research and development of fuel  
cell technology as a replacement for combustion-based energy  
sources.【】1  
A fuel cell is an electrochemical device that converts  
chemical energy via an oxidation process (at the anode) and a  
corresponding reduction (at the cathode) of a fuel into  
electrical energy. A prominent example of a functional fuel cell  
configuration is the proton exchange membrane fuel cell  
(PEMFC).2−4 In PEMFCs, the oxygen reduction reaction  
(ORR), localized at the cathode, requires higher overpotentials  
in order to initiate the reaction as compared with the hydrogen  
oxidation reaction (HOR) occurring at the anode, and  
therefore denotes the rate limiting “step”.5 In other words,  
the process required to initiate ORR is especially energy  
intensive. Not surprisingly, the development of new and more  
effective electrocatalysts at the cathode has received significant  
research and developmental attention.6

【现有电催化剂体系】

【现有电催化剂体系】

[33] L. Li, H. Liu, L. Wang, S. Yue, X. Tong, T. Zaliznyak, G. T. Taylor, S. S. Wong, Chemical Strategies for Enhancing Activity and Charge Transfer in Ultrathin Pt Nanowires Immobilized onto Nanotube Supports for the Oxygen Reduction Reaction, ACS Applied Materials and Interfaces, 2016, 8: 34280-34294.

State-of-the-art cathodic electrocatalysts primarily consist of  
nanostructured precious metals (e.g., Pt) and associated metal  
alloys supported onto commercial carbon supports, due to their  
high catalytic activity and reasonable durability in a highly  
acidic, high-oxygen concentration environment. 【1d纳米材料优势，文献】

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[33] L. Li, H. Liu, L. Wang, S. Yue, X. Tong, T. Zaliznyak, G. T. Taylor, S. S. Wong, Chemical Strategies for Enhancing Activity and Charge Transfer in Ultrathin Pt Nanowires Immobilized onto Nanotube Supports for the Oxygen Reduction Reaction, ACS Applied Materials and Interfaces, 2016, 8: 34280-34294.

Specifically, a  
lot of work has centered on anisotropic one-dimensional  
structures, such as nanowires (NWs) and nanotubes (NTs),  
because crystalline 1D nanostructures possess higher aspect  
ratios, fewer lattice boundaries, longer segments of smooth  
crystal planes, and a lower number of surface defect sites than  
their nanoparticulate (NP) analogues, all of which denote  
advantageous attributes for fuel cell catalysts.7 −10 In particular, in our lab, we have expended a good deal of  
effort in developing ultrathin Pt-based nanowires (average  
diameters less than 5 nm) as viable structural motifs to not only  
maximize the surface area-to-volume ratio but also decrease the  
amount of catalytically inaccessible material within the interior  
of the wire. The inherent structural traits of ultrathin nanowires  
can induce superior activity in these systems as compared with  
both larger Pt nanotubes, as well as Pt nanoparticles.11 【文献中不同纳米线的对比】

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As one  
key salient example relevant to the current paper, we  
demonstrated that our ultrathin, acid-treated, unsupported  
nanowires could achieve a surface area activity value of as high  
as 1.45 mA/cm2, which was nearly 4 and 7 times greater than  
that of analogous, unsupported 200 nm-diameter Pt NTs and of  
supported commercial Pt NPs ( ∼3 nm in average diameter,  
immobilized onto a Vulcan XC-72 substrate with a Pt loading  
of 20% by mass), respectively.  
【Pt的发展目标】

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[33] L. Li, H. Liu, L. Wang, S. Yue, X. Tong, T. Zaliznyak, G. T. Taylor, S. S. Wong, Chemical Strategies for Enhancing Activity and Charge Transfer in Ultrathin Pt Nanowires Immobilized onto Nanotube Supports for the Oxygen Reduction Reaction, ACS Applied Materials and Interfaces, 2016, 8: 34280-34294.

While these advances in catalyst synthesis are important and  
necessary, the fundamental challenge remains as to how to  
maintain or improve catalyst activity and durability, while  
simultaneously reducing or eliminating Pt loading. 【】One  
intriguing approach is to develop an “optimized” support  
material onto which these Pt NPs, NWs, and NTs are  
immobilized. Specifically, the conventional commercial supporting material itself, such as Vulcan carbon, can be prone to  
undergo damage and destruction in acidic media. In other  
words, even though carbon black (CB) can potentially assist in  
minimizing catalyst aggregation and dissolution, it unfortunately is also susceptible to undergoing electrochemical  
oxidation to surface oxides and ultimately, to CO2. Indeed,  
catalyst failure can often be attributed to the corrosion of  
carbon substrates. Specifically, the structural and chemical  
integrity of traditional carbon-supported catalysts can be  
affected by changes in temperature, pH, and potential in  
addition to the water content and purity of the immobilized  
catalyst itself.12  
The idea to mitigate for all of these issues would be to  
rationally design supports for which one can induce favorable  
catalyst −support interactions. Carbon nanotubes (CNTs)  
represent a model support medium for ORR catalysts because  
of a number of desirable attributes, including but not limited to  
their high surface area, reasonable electronic conductivity, as  
well as their relatively high stability and corrosion resistance  
when exposed to an acidic environment.13 −16 Multiwalled  
carbon nanotubes (MWNTs) are typically used by comparison  
with either their single-walled or double-walled CNT counterparts, since MWNTs are known to be durable and conductive  
as well as structurally robust, and can be more uniformly  
dispersed within a functioning reaction environment.17  
As opposed to raw unprocessed CNTs, surface functionalized  
CNTs are even more appealing as catalyst supports due to their  
potential for “anchoring” and favorably influencing the  
subsequent activity and robustness of immobilized catalyst  
particles, such as Pt NPs.12 For instance, theoretical DFT  
calculations18 have predicted that the presence of SH groups on  
CNTs can not only restrict particle migration but also enhance  
the oxidative resistance of Pt clusters attached onto these  
derivatized CNTs. Specifically, by inhibiting Pt −O and Pt −OH  
formation, the greater observed stability of this architecture  
likely emanates from (i) an increased interaction between Pt  
and SH −CNTs, as well as from (ii) a depressed d-band center  
of the Pt NPs.  
Hence, surface functionalization of either the support or the  
catalyst particle itself should hopefully help to achieve (a) a  
more uniform dispersion of metallic catalysts, as well as (b)  
protection from both dissolution and/or degradation, thereby  
implying higher durability as compared with their pristine  
counterparts.19,20 An additional benefit that we seek to fully  
explore herein would be the presence of chemically induced  
electrocatalytic enhancement, which could be ascribed to  
favorable electronic interactions between the associated catalyst  
and the underlying substrate.  
Experimentally, the nature of the surface functionalization  
yields a number of interesting results. As an example, Pt  
particles have previously been immobilized onto CNTs using  
an intervening triphenylphosphine (PPh3) linker, because the  
PPh  
3 moiety can assist in solubilizing Pt, prevent its  
aggregation, and furthermore, help in creating a uniform  
distribution of NPs on the underlying CNT surface, which  
collectively increase their intrinsic tolerance to impurity  
carbonaceous species.21 Other relevant examples include the  
use of polymers,22 such as ionic-liquid polymers (PIL),23,24 as  
well as small organic molecules, such as 4-nitrophenyl groups,25  
sodium dodecyl sulfate,26,27 and phthalocyanines,28 to facilitate  
the immobilization of Pt NPs onto the CNT surface.  
Using X-ray photoelectron spectroscopy (XPS), Guo et al.  
found that PtRu catalysts anchored onto carbon nanotubes,  
functionalized by both thiol groups (SH) and carboxylic acid  
groups (COOH), show varying affinities in terms of binding  
potentially poisonous CO species. Specifically, based upon the  
Pt 4f  
7/2 peak shifting to a higher binding energy for the −SH  
functionalized CNTs, it was suggested that back-donation from  
the Pt to the CO was lessened, because Pt interacts strongly  
with −SH. Such a scenario ultimately resulted in a favorably  
weakened binding of Pt to CO as compared with the  
corresponding COOH-functionalized CNTs. Guo’s work also  
provided important insight into the direction of charge transfer  
within the functionalized CNT-based heterostructures. In  
effect, the S 2p shift to lower energy within SH −CNT relative  
to that of Pt −SH −CNT itself implied charge movement from  
the catalytic Pt NPs to the attached SH −CNT support.  
These XPS data collectively illustrate that surface terminating  
moieties can not only facilitate the dispersion of the NPs onto  
the underlying support but also can affect the catalyst’s inherent  
electronic character, all of which have a direct impact upon  
catalysis.29 Hence, the focus of this paper is on systematically  
understanding the important and perhaps less well-understood  
“intermixing” of the electronic structures of the immobilized  
catalysts with that of the underlying catalytic supports. We  
intend to probe these relatively poorly understood interactions  
as a function not only of the precise terminal chemistry of the  
CNT supports themselves but also of the exact means used to  
couple our Pt catalysts with the underlying CNT surfaces.  
Most of the prior literature has focused on forming covalent  
linkages between the MWNTs and their terminal end groups.

Specifi cally, MWNTs have been initially oxidized to yield  
oxygenated carboxylic acid groups on their outer surface (i.e.,  
COOH − MWNTs) and then further modifi ed with an array of  
additional functional groups, such as but not limited to  
h y d r o x i d e ( − O H ) , t h i o l ( − S H ) , a n d a m i n e ( − N H2)  
moieties.30,31 Nonetheless, studies have demonstrated that  
such harsh surface modifications can give rise to two main  
disadvantages. First, the initial acid treatment may inevitably  
engender an increase in the number and percentage of surface  
defects on the MWNTs, which in turn can cause the loss of  
both conductivity and structural integrity of the nanotubes,  
thereby resulting in a loss of activity as well as of long-term  
stability.32 Moreover, dangling bonds formed during the  
covalent functionalization process can easily be oxidized and  
thereby induce a greater degree of surface corrosion under  
standard electrochemical conditions.33 Second, the carboxyl  
groups tend to localize onto existing defect sites, which may  
affect the resulting dispersion of deposited Pt nanostructures.  
Herein, we have utilized two distinctive methods (i.e., a  
c o v a l e n t, reflux-mediated approach versus a noncovalent,  
sonication-based technique) of coupling MWNTs with the  
various types of ligands that contains common terminal  
functional groups, including carboxylic acids, amines, and  
thiols. We found that these noncovalently generated supports  
display superior performance toward ORR as compared with  
their covalently formed, reflux-based CNT counterparts. We  
have subsequently probed the electronic structures of the asformed catalyst −support combinations, through optical characterization techniques including XPS and Raman spectroscopy. As a model system, we have deposited our as-prepared  
ultrathin (average diameter ∼2 nm) Pt nanowires onto these  
variously functionalized MWNTs to investigate the impact of  
modifying not only (a) the terminal ligand moiety but also (b)  
the attachment approach. That is, we view the purposeful  
alteration of the substrate’s electronic structure as an attractive  
and perhaps less studied variable with which to enhance  
electrocatalytic performance.  
Moreover, as an additional and key element of novelty within  
our work, we highlight that prior studies have usually analyzed  
the deposition of Pt NPs onto various types of substrates (i.e.,  
our control experiments herein). By contrast, we have focused  
our efforts on our high-performing, as-prepared ultrathin Pt  
NWs. Hence, for the first time, we have investigated hitherto  
unknown NW catalyst-functionalized MWNT support interactions in ORR. Our results indicate that electron transfer  
processes do in fact occur in these systems, due to the presence  
of the various terminal functionalities. Most interestingly, not  
only the direction of the observed charge transfer but also the  
observed ORR performance appears to depend to a large  
degree on the precise attachment (i.e., covalent vs noncovalent)  
methodology used to connect the NW catalyst with the  
underlying catalyst support.  
In terms of activity benchmarks, the specific activities of Pt  
NPs supported on MWNTs usually vary in a range from 0.3 to  
0.6 mA/cm2, depending upon the specific surface modifications  
of the supports, which are respectively characterized by pendant  
−NH  
2, −COOH, −OH, and −SH moieties.30,31,34,35 Herein,  
our best result was noted with Pt NWs dispersed onto COOHfunctionalized MWNTs with a physical sonication method. In  
effect, the measured activity (i.e., 1.54 mA/cm2) on these  
derivatized supports was more than (i) 2-fold greater as  
compared with similarly dispersed Pt NWs on raw MWNTs  
and more than (ii) 5-fold higher than what is normally  
associated with conventional Pt NPs supported onto raw  
MWNTs. Moreover, to the best of our knowledge, our data  
have surpassed any previously reported results on comparable  
systems composed of nanoscale Pt metal catalysts coupled with  
carbonaceous supports. We believe that this reproducible  
enhancement originates from a positively synergistic and  
favorable interaction between morphological and chemical  
effects. Moreover, our data may also yield promise for the  
development of 1D-1D heterostructures as architecturally  
viable electrochemical motifs.

## [34] M. A. Hoque, F. M. Hassan, M. H. Seo, J. Y. Choi, M. Pritzker, S. Knights, S. Ye, Z. Chen, Optimization of sulfur-doped graphene as an emerging platinum nanowires support for oxygen reduction reaction, Nano Energy, 2016, 19: 27-38.

Introduction  
【为满足燃料电池，动力学限制需要解决】

【为满足燃料电池，动力学限制需要解决】

[34] M. A. Hoque, F. M. Hassan, M. H. Seo, J. Y. Choi, M. Pritzker, S. Knights, S. Ye, Z. Chen, Optimization of sulfur-doped graphene as an emerging platinum nanowires support for oxygen reduction reaction, Nano Energy, 2016, 19: 27-38.

The kinetic limitations of the cathodic oxygen reduction reaction (ORR) must be overcome to meet the practical  
demands for polymer electrolyte membrane fuel cells

(PEMFC s) [1–5].【过电位归因于缓慢的动力学】

【过电位归因于缓慢的动力学】

[34] M. A. Hoque, F. M. Hassan, M. H. Seo, J. Y. Choi, M. Pritzker, S. Knights, S. Ye, Z. Chen, Optimization of sulfur-doped graphene as an emerging platinum nanowires support for oxygen reduction reaction, Nano Energy, 2016, 19: 27-38.

The observed overpotential is attributed to  
the slow kinetics of ORR occurring on the conventional carbon  
supported platinum nanoparticle (Pt/C) catalysts [6–8]. 【Pt/C纳米颗粒的活性具有缺点的原因】

【Pt/C纳米颗粒的活性具有缺点的原因】

[34] M. A. Hoque, F. M. Hassan, M. H. Seo, J. Y. Choi, M. Pritzker, S. Knights, S. Ye, Z. Chen, Optimization of sulfur-doped graphene as an emerging platinum nanowires support for oxygen reduction reaction, Nano Energy, 2016, 19: 27-38.

These  
zero dimensional (0D) nanoparticulate electrocatalysts lack  
activity due to a high number of defect sites, lattice  
boundaries and low coordination atoms on the surface that  
results from their very small size. This leads to the strong  
adsorption of oxygen containing species (i.e., OH groups) and  
thereby decreases the number of active platinum sites  
available for the ORR [9–12]. 【Pt/C纳米颗粒稳定性具有缺点的原因】

【Pt/C纳米颗粒稳定性具有缺点的原因】

[34] M. A. Hoque, F. M. Hassan, M. H. Seo, J. Y. Choi, M. Pritzker, S. Knights, S. Ye, Z. Chen, Optimization of sulfur-doped graphene as an emerging platinum nanowires support for oxygen reduction reaction, Nano Energy, 2016, 19: 27-38.

Stability is another pertinent  
concern, whereby Pt/C degrades during PEMFC operation due  
to carbon corrosion and/or platinum nanoparticles agglomeration, dissolution and Ostwald ripening [13–15].  
 【纳米线优势】

【纳米线优势】

[34] M. A. Hoque, F. M. Hassan, M. H. Seo, J. Y. Choi, M. Pritzker, S. Knights, S. Ye, Z. Chen, Optimization of sulfur-doped graphene as an emerging platinum nanowires support for oxygen reduction reaction, Nano Energy, 2016, 19: 27-38.

In contrast to nanoparticles, one dimensional (1D) nanostructures, such as platinum nanowires, have been highly touted  
as promising solutions to the inherent activity and durability  
issues associated with state-of-the-art nanoparticle catalysts  
[16–21]. These 1D platinum morphologies provide significant  
advantages owing to their unique anisotropic structure and  
surface properties that lead to excellent electrocatalytic  
activity and durability [9,22,23]. In particular, platinum nanowire morphologies minimize the number of undesirable low coordination defect sites due to their preferential exposure of smooth crystalline planes [24–26]. Therefore, the cathodic overpotential caused by adsorbed oxygen-containing species  
can be significantly suppressed, leading to an increase in ORR  
kinetics [27,28]. 【纳米线生长在碳基体有利于进一步提高活性】

【纳米线生长在碳基体有利于进一步提高活性】

[34] M. A. Hoque, F. M. Hassan, M. H. Seo, J. Y. Choi, M. Pritzker, S. Knights, S. Ye, Z. Chen, Optimization of sulfur-doped graphene as an emerging platinum nanowires support for oxygen reduction reaction, Nano Energy, 2016, 19: 27-38.

The performance of platinum nanoparticles or nanowires  
can be further improved by growing them onto a variety of  
stable supports, including mesoporous carbon, carbon nanofibers, carbon nanotubes and graphene [29–36]. Among  
these supports, graphene has significant application potential owing to its unique properties [37]. 【】The two dimensional  
sp2 bonded hybridized carbon network in particular possesses outstanding mechanical, chemical and electrical  
properties that are ideal for electrochemical applications  
[38].【理论和实验都表明异质原子掺杂石墨烯改善性能】

【理论和实验都表明异质原子掺杂石墨烯改善性能】

[34] M. A. Hoque, F. M. Hassan, M. H. Seo, J. Y. Choi, M. Pritzker, S. Knights, S. Ye, Z. Chen, Optimization of sulfur-doped graphene as an emerging platinum nanowires support for oxygen reduction reaction, Nano Energy, 2016, 19: 27-38.

Both theoretical calculations and detailed experiments  
have shown that the intrinsic properties of graphene can be  
modified by the introduction of heteroatoms, such as sulfur,  
nitrogen, phosphorus or boron into the carbon frameworks  
[32,39–41]. 【大量研究致力于N掺杂碳的研究】

【大量研究致力于N掺杂碳的研究】

[34] M. A. Hoque, F. M. Hassan, M. H. Seo, J. Y. Choi, M. Pritzker, S. Knights, S. Ye, Z. Chen, Optimization of sulfur-doped graphene as an emerging platinum nanowires support for oxygen reduction reaction, Nano Energy, 2016, 19: 27-38.

A lot of research has been carried out to  
investigate nitrogen doped carbon materials as platinum  
catalyst supports, with enhancements to both ORR activity  
and electrochemical stability observed [42–46]. We were  
however the first to develop sulfur-doped graphene (SG) as  
a platinum catalyst support, capable of providing remarkable activity and durability improvements [32,33]. 【DFT和实验研究表明…】

【DFT和实验研究表明…】

[34] M. A. Hoque, F. M. Hassan, M. H. Seo, J. Y. Choi, M. Pritzker, S. Knights, S. Ye, Z. Chen, Optimization of sulfur-doped graphene as an emerging platinum nanowires support for oxygen reduction reaction, Nano Energy, 2016, 19: 27-38.

Through  
detailed density functional theory (DFT) calculations and  
experimental investigations, we demonstrated that platinum binds strongly to SG. These strong catalyst-support  
interactions lead to an enhancement in Pt stabilization,  
along with modulated electronic properties that provide  
ORR activity enhancements. 【】The amount of sulfur in SG very  
likely has a significant impact on the interactions with  
platinum, owing to its influence on the electrical and  
chemical properties of the resulting catalyst. Therefore,  
detailed knowledge of the sulfur concentration dependency  
of the electro-kinetic parameters for oxygen reduction,  
along with the physichochemical properties of the developed catalysts is of importance. This fundamental insight is  
essential to the design and development of optimal Pt–SG  
catalysts.  
【本文，我们阐明了…对性能的作用.】

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[34] M. A. Hoque, F. M. Hassan, M. H. Seo, J. Y. Choi, M. Pritzker, S. Knights, S. Ye, Z. Chen, Optimization of sulfur-doped graphene as an emerging platinum nanowires support for oxygen reduction reaction, Nano Energy, 2016, 19: 27-38.

In this report, we provide an extensive investigation to  
elucidate the effect of sulfur concentration on the oxygen  
reduction performance of SG supported platinum nanowires  
(PtNW/SG). 【本文，结构性能表征】

【本文，结构性能表征】

[34] M. A. Hoque, F. M. Hassan, M. H. Seo, J. Y. Choi, M. Pritzker, S. Knights, S. Ye, Z. Chen, Optimization of sulfur-doped graphene as an emerging platinum nanowires support for oxygen reduction reaction, Nano Energy, 2016, 19: 27-38.

We examine the morphologies, structural and  
electrical properties of PtNW/SG with different sulfur contents, and then investigated the electrochemical kinetic parameters such as Tafel slope, exchange current density and ctivation energy towards oxygen reduction. These detailed  
experimental investigations are also linked to computational  
simulations to systematically elucidate the impact and contribution of sulfur on the ORR activity of PtNW catalysts. 【】

## [35] K. Hassan, A. S. M. I. Uddin, G. S. Chung, Hydrogen sensing properties of Pt/Pd bimetal decorated on highly hydrophobic Si nanowires, International Journal of Hydrogen Energy, 2016, 41: 10991-11001.

Introduction  
The growth of nanotechnology has stimulated various opportunities for developing gas sensors with significantly  
upgraded performances.【1D纳米结构优势】

【1D纳米结构优势】

[35] K. Hassan, A. S. M. I. Uddin, G. S. Chung, Hydrogen sensing properties of Pt/Pd bimetal decorated on highly hydrophobic Si nanowires, International Journal of Hydrogen Energy, 2016, 41: 10991-11001.

For this purpose, one dimension (1D)  
nanostructures including nanorods/nanowires [1e3] and  
nanotubes [4,5] have been exclusively studied because of their  
large surface-to-volume ratio and nanoscale dimensions.【】  
Among of various metal catalysts, palladium (Pd) has become  
the most promising candidate for H2 detection. To date,  
numerous studies on 1D Pd nanostructures have been carried  
out to synthesize Pd nanowires with good quality [6e12] using  
the pressure-injection or electrodeposition of Pd into  
nanochannels of porous membranes [6,7], electrode  
patterning followed by dielectrophoresis [8,9], top-down  
patterning from a Pd thin film using E-beam lithography  
[10e12], etc. Recently, various research groups have developed  
and presented single Pd nanowires that have attracted significant attention in hydrogen sensing mechanisms due to their fast response time and high response magnitude [13-17]. However, these methods all include complex nanowire growth and nanodevice fabrication processes, which  
may hinder their practical applications. Conversely, the  
sensitivity of a single Pd nanowire is insufficient to assure the  
amplified output signals. To overcome these shortcomings, a  
large number of research groups worked on Pd based thin film

hydrogen (H2) sensors because of their catalytic interaction  
and diverse properties such as strong adhesion with a large  
diffusion coefficient and low activation barrier [18e28]. However, at higher concentrations, the adsorption capability of H2  
molecules is restrained; consequently, the desired outcomes  
cannot be attained [29].  
More importantly, lattice expansion and contraction during hydrogenation and dehydrogenation make Pd susceptible  
to mechanical and topographical instability, while platinum  
(Pt) with a high specific surface area and good mechanical  
strength can be a possible mean to provide an ideal support  
layer for Pd during H2 sensing. In addition, PtePd is known to  
show better hydrogenation property in comparison to pure Pd.  
On the other hand, Pd is scarce and expensive, and its use  
therefore needs to be minimized. For this reason, Pt/Pd  
bimetallic heterogeneous structures were proposed, which  
showed promise as potential catalysts in hydrogen sensing  
[22]. In addition, Pt/Pd thin film is well suited for the enhanced  
kinetic absorption of H2 gas molecules and thus significant  
changes can occur in its electrical properties [30,31]. The  
operation mechanism of thin film resistive sensors depends  
on the interaction of gaseous atoms with a thin film surface,  
which influences surface potential and surface conductivity  
because of the changes in the charge concentration of free  
electrons [29,32]. In a thin layer, the charge exchange takes  
place underneath the gasesolid interface. The response of  
sensor depends on the gas diffusion, adsorption, and reaction  
of the adsorbed molecules [33e37]. For this reason, to develop  
a fast response gas sensor, the film surface needs to have a  
large specific area (surface area to volume ratio) to obtain a  
higher charge exchange rate, which can be achieved by using  
porous substrates [38]. Particularly, for the fast response H2  
sensor, porous silicon substrates with the decoration of  
different nanomaterials and nanostructures can represent a  
promising scheme because of the ease of integration, low cost,  
and high specific area of the base material [39e41].  
In the current work, we deposited uniform Pt/Pd bimetallic  
nanoparticles in a discrete ultra-thin film manner on highly  
hydrophobic vertical-standing silicon nanowires (Si NWs)  
using the pulsed laser deposition (PLD) technique. The hydrophobic Si NWs substrate is expected to provide higher gas  
diffusion, adsorption, and reaction to adsorbed molecules  
with local film adhesion to the substrate at high pressure. In  
addition, the discrete Pt/Pd ultra-thin film is expected to show  
possible enhancements due to the synergetic interplay between the bi-functional capping configuration, large surfaceto-volume ratio, and quantum size of the nanoparticles. The  
as-fabricated structure was used as a resistivity-type sensor  
with the aim of developing a high performance H2 sensor with  
fast response-recovery time

## [36] J. Lai, L. Zhang, W. Qi, J. Zhao, M. Xu, W. Gao, G. Xu, Facile synthesis of porous PtM (M=Cu, Ni) nanowires and their application as efficient electrocatalysts for methanol electrooxidation, ChemCatChem, 2014, 6: 2253-2257.

【Pt高效催化剂】

【Pt高效催化剂】

[36] J. Lai, L. Zhang, W. Qi, J. Zhao, M. Xu, W. Gao, G. Xu, Facile synthesis of porous PtM (M=Cu, Ni) nanowires and their application as efficient electrocatalysts for methanol electrooxidation, ChemCatChem, 2014, 6: 2253-2257.

Platinum (Pt) and its composites are most promising catalysts  
in fuel cells and other heterogeneous catalytic processes.【Pt成本高，不足的活性和稳定性商业化存在挑战】

【Pt成本高，不足的活性和稳定性商业化存在挑战】

[36] J. Lai, L. Zhang, W. Qi, J. Zhao, M. Xu, W. Gao, G. Xu, Facile synthesis of porous PtM (M=Cu, Ni) nanowires and their application as efficient electrocatalysts for methanol electrooxidation, ChemCatChem, 2014, 6: 2253-2257.

Nevertheless, the high cost as well as the insufficient catalytic activity and stability of Pt catalysts pose a severe challenge for broad applications.[1] 【各种策略用于减少用量和提高活性，文献】

【各种策略用于减少用量和提高活性，文献】

[36] J. Lai, L. Zhang, W. Qi, J. Zhao, M. Xu, W. Gao, G. Xu, Facile synthesis of porous PtM (M=Cu, Ni) nanowires and their application as efficient electrocatalysts for methanol electrooxidation, ChemCatChem, 2014, 6: 2253-2257.

Various strategies have thus been developed to improve the catalytic activity and stability of Pt catalysts and decrease the Pt loading.[2–13] For example, the addition of a second cheap 3d transition metal (e.g., Fe, Co, Ni, Cu) to Pt to form Pt-based heteronanostructures or alloy catalysts  
could decrease the Pt loading and increase the catalytic activity and poisoning resistance.[14–16] 【1D和多孔优势】

【1D和多孔优势】

[36] J. Lai, L. Zhang, W. Qi, J. Zhao, M. Xu, W. Gao, G. Xu, Facile synthesis of porous PtM (M=Cu, Ni) nanowires and their application as efficient electrocatalysts for methanol electrooxidation, ChemCatChem, 2014, 6: 2253-2257.

If Pt is present as one-dimensional (1 D) nanostructures such as nanowires, its durability is  
greatly enhanced.[17–31] Porous structures have also been widely  
employed to enhance catalytic properties owing to their high  
surface area and rich edge/corner atoms.[32–35] 【1D多孔结构的制备方法及缺点】

【1D多孔结构的制备方法及缺点】

[36] J. Lai, L. Zhang, W. Qi, J. Zhao, M. Xu, W. Gao, G. Xu, Facile synthesis of porous PtM (M=Cu, Ni) nanowires and their application as efficient electrocatalysts for methanol electrooxidation, ChemCatChem, 2014, 6: 2253-2257.

The combination  
of 1D nanostructures and porous structures may further improve performance. However, only a few methods have been  
developed for the synthesis of porous Pt-based 1 D nanostructures, such as the electrodeposition method,[24, 30, 31] electrospinning, and a chemical dealloying process.[25] Most reported methods for the synthesis of porous Pt-based nanowires require complicated procedures. 【无稳定剂、模板制备方法未被报道】

【无稳定剂、模板制备方法未被报道】

[36] J. Lai, L. Zhang, W. Qi, J. Zhao, M. Xu, W. Gao, G. Xu, Facile synthesis of porous PtM (M=Cu, Ni) nanowires and their application as efficient electrocatalysts for methanol electrooxidation, ChemCatChem, 2014, 6: 2253-2257.

To the best of our knowledge,  
one-step synthetic methods without stabilizers, templates, or  
external fields for the preparation of porous Pt-based nanowires have never been reported.【】  
 【本文，报道了一步合成多孔纳米线….】

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[36] J. Lai, L. Zhang, W. Qi, J. Zhao, M. Xu, W. Gao, G. Xu, Facile synthesis of porous PtM (M=Cu, Ni) nanowires and their application as efficient electrocatalysts for methanol electrooxidation, ChemCatChem, 2014, 6: 2253-2257.

Herein, we report the one-step synthesis of porous PtM (M =Cu, Ni) nanowires for the first time.【本文，制备方法】

【本文，制备方法】

[36] J. Lai, L. Zhang, W. Qi, J. Zhao, M. Xu, W. Gao, G. Xu, Facile synthesis of porous PtM (M=Cu, Ni) nanowires and their application as efficient electrocatalysts for methanol electrooxidation, ChemCatChem, 2014, 6: 2253-2257.

The porous PtM (M = Cu, Ni) nanowires were synthesized by solvothermal reaction. The  
combination of a nanowire structure, porous structure, and the  
addition of a second cheap metal improves the electrocatalytic  
activity and durability and saves cost. 【本文，电化学活性】

【本文，电化学活性】

[36] J. Lai, L. Zhang, W. Qi, J. Zhao, M. Xu, W. Gao, G. Xu, Facile synthesis of porous PtM (M=Cu, Ni) nanowires and their application as efficient electrocatalysts for methanol electrooxidation, ChemCatChem, 2014, 6: 2253-2257.

The application of  
porous PtM (M = Cu, Ni) nanowires for the electrocatalytic  
methanol oxidation reaction (MOR) was studied. The obtained  
porous PtM (M = Cu, Ni) alloy nanowires can act as highly effective catalysts for the MOR. 【】

## [37] C. Zhu, S. Guo, S. Dong, PdM (M = Pt, Au) bimetallic alloy nanowires with enhanced electrocatalytic activity for electro-oxidation of small molecules, Advanced Materials, 2012, 24: 2326-2331.

【精确尺寸、形状和成分可控可以调控性能】

【精确尺寸、形状和成分可控可以调控性能】

[37] C. Zhu, S. Guo, S. Dong, PdM (M = Pt, Au) bimetallic alloy nanowires with enhanced electrocatalytic activity for electro-oxidation of small molecules, Advanced Materials, 2012, 24: 2326-2331.

Recent advances revealed that accurately controlling the size,  
shape, and composition allows the properties of various noble  
metals to be varied, and to provide enormous opportunities for  
tailoring their properties, thus enhancing their functions and  
application performance.[1,2] 【】Compared to single-metal systems, rational design of bimetallic nanostructures with various  
compositions can provide more attractive opportunities for further enhancement of their functionalities owing to their novel  
optical, catalytic, electronic, and magnetic properties. Particularly, a prominent example is Pd-based bimetallic nanostructures, which have been extensively investigated because of their  
potential technological applications, including as catalysts in  
many chemical reactions[1] and as electrode materials in fuel  
cells.[2] To date, considerate effects have been made to synthesize  
high-effi ciency Pd-based bimetallic core–shell nanostructures  
with various morphologies, such as nanotubes,[3] nanowires,[4]  
nanodendrites[5] and so on. Meanwhile, as a signifi cant type of  
bimetallic nanostructures, alloy nanostructures have recently  
received increasing attention because of their effi cient catalytic  
properties.[6] 【双金属形状可控合成…方法有限，存在挑战】

【双金属形状可控合成…方法有限，存在挑战】

[37] C. Zhu, S. Guo, S. Dong, PdM (M = Pt, Au) bimetallic alloy nanowires with enhanced electrocatalytic activity for electro-oxidation of small molecules, Advanced Materials, 2012, 24: 2326-2331.

However, developing a facile and general approach  
to synthesize Pd-based bimetallic alloy nanostructures with  
controlled size and shape has only a limited success and is still  
a grand challenge for the development of multifunctional smart  
materials.[7]   
【纳米线受关注，由于具有优势】

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[37] C. Zhu, S. Guo, S. Dong, PdM (M = Pt, Au) bimetallic alloy nanowires with enhanced electrocatalytic activity for electro-oxidation of small molecules, Advanced Materials, 2012, 24: 2326-2331.

On the other hand, one-dimensional (1D) noble metal  
nanowires have attracted much attention due to their various  
potential applications deriving from their unique properties in comparison with their associated 0D morphologies.[8] 【纳米线合成方法，及模板法优势】

【纳米线合成方法，及模板法优势】

[37] C. Zhu, S. Guo, S. Dong, PdM (M = Pt, Au) bimetallic alloy nanowires with enhanced electrocatalytic activity for electro-oxidation of small molecules, Advanced Materials, 2012, 24: 2326-2331.

Currently, various protocols have been explored to synthesize high-effi ciency 1D Pd-based nanostructures such as wetchemical strategy,[9] template directed approach,[10] modified  
phase-transfer method,[11] and so on.[8a] Among these methods,  
template-directed approach was recognized as a promising  
alternative to synthesize both monometallic and bimetallic  
alloy nanostructures, since the size and shape of the desired  
materials can be easily directed using a well-defi ned template  
matrix. In a procedure to synthesize alloy nanostructures based  
on the template-engaged approach, the template (e.g., Ag and  
Cu nanostructures)[12] can be converted to another metal with  
similar morphology via galvanic replacement reaction. These  
as-prepared alloy nanostructures usually limited to one metal  
precursor, which interacted with template to form alloy nanostructures.【高质量的合金纳米线合成没有被报道】

【高质量的合金纳米线合成没有被报道】

[37] C. Zhu, S. Guo, S. Dong, PdM (M = Pt, Au) bimetallic alloy nanowires with enhanced electrocatalytic activity for electro-oxidation of small molecules, Advanced Materials, 2012, 24: 2326-2331.

Little work focuses on the impact of two or more  
metal precursors on the template in the process of alloy formation. In particular, to the best of our knowledge, there are no  
successful demonstration in the preparation of high-quality 1D  
Pd-based alloy nanostructures with uniform diameter and high  
aspect ratios.  
【本文，发展了一种合金纳米线制备方法】

【本文，发展了一种合金纳米线制备方法】

[37] C. Zhu, S. Guo, S. Dong, PdM (M = Pt, Au) bimetallic alloy nanowires with enhanced electrocatalytic activity for electro-oxidation of small molecules, Advanced Materials, 2012, 24: 2326-2331.

Herein, we developed a facile method for synthesizing the aspect ratio of 1D Pd-based alloy nanowires (ANWs) including  
PdPt and PdAu using Te NWs as a sacrificial template and  
reducing agent. 【本文，系统研究。。。对形貌的影响】

【本文，系统研究。。。对形貌的影响】

[37] C. Zhu, S. Guo, S. Dong, PdM (M = Pt, Au) bimetallic alloy nanowires with enhanced electrocatalytic activity for electro-oxidation of small molecules, Advanced Materials, 2012, 24: 2326-2331.

We systematically investigated the various  
noble metal precursors and solvent on the morphology of  
fi nal products and successfully synthesize Pd-based ANWs in  
aqueous solution at room temperature. 【本文，电化学活性】

【本文，电化学活性】

[37] C. Zhu, S. Guo, S. Dong, PdM (M = Pt, Au) bimetallic alloy nanowires with enhanced electrocatalytic activity for electro-oxidation of small molecules, Advanced Materials, 2012, 24: 2326-2331.

Significantly, the as-prepared Pd-based ANWs exhibited significantly enhanced  
activity towards small molecules, such as ethanol, methanol and  
glucose electro-oxidation in alkaline medium, demonstrating the  
potential of applying these Pd-based ANWs as effective electrocatalysts for direct alcohol fuel cells (DAFCs) and as enhanced nanomaterials for constructing a promising electrochemical sensor with high sensitivity for nonenzymatic glucose.【】

## [38] B. Y. Xia, W. T. Ng, H. B. Wu, X. Wang, X. W. Lou, Self-supported interconnected Pt nanoassemblies as highly stable electrocatalysts for low-temperature fuel cells, Angewandte Chemie - International Edition, 2012, 51: 7213-7216.

【燃料电池受到广泛关注】

【燃料电池受到广泛关注】

[38] B. Y. Xia, W. T. Ng, H. B. Wu, X. Wang, X. W. Lou, Self-supported interconnected Pt nanoassemblies as highly stable electrocatalysts for low-temperature fuel cells, Angewandte Chemie - International Edition, 2012, 51: 7213-7216.

Low-temperature fuel cells have attracted considerable  
attention because of their high power density, low operating  
temperature ( < 1208C), and reduced pollution as a new  
power source for automobiles and portable electronic devices.[1,2] 【差活性和稳定性阻碍了商业化】

【差活性和稳定性阻碍了商业化】

[38] B. Y. Xia, W. T. Ng, H. B. Wu, X. Wang, X. W. Lou, Self-supported interconnected Pt nanoassemblies as highly stable electrocatalysts for low-temperature fuel cells, Angewandte Chemie - International Edition, 2012, 51: 7213-7216.

However, their commercialization is impeded by the  
poor durability and activity of electrocatalysts.[2–4] State-ofthe-art electrocatalysts primarily consist of Pt nanoparticles  
(NPs) supported on carbon black (Pt/CB).[5] 【pt/CB不稳定性反映在活性面积的快速损失和活性的下降，主要是C被腐蚀】

【pt/CB不稳定性反映在活性面积的快速损失和活性的下降，主要是C被腐蚀】

[38] B. Y. Xia, W. T. Ng, H. B. Wu, X. Wang, X. W. Lou, Self-supported interconnected Pt nanoassemblies as highly stable electrocatalysts for low-temperature fuel cells, Angewandte Chemie - International Edition, 2012, 51: 7213-7216.

The poor durability of Pt/CB catalysts is reflected in a fast and  
significant loss of electrochemical surface area (ECSA) and  
thus degradation of the fuel cells performance. It has been  
argued that the loss of ECSA is mainly ascribed to the  
corrosion of carbon supports, which further results in migration, aggregation, and Ostwald ripening of Pt NPs because of  
their high surface energy and zero-dimensional (0D) structural features.[6,7]【纳米线的优势，提高稳定性】

【纳米线的优势，提高稳定性】

[38] B. Y. Xia, W. T. Ng, H. B. Wu, X. Wang, X. W. Lou, Self-supported interconnected Pt nanoassemblies as highly stable electrocatalysts for low-temperature fuel cells, Angewandte Chemie - International Edition, 2012, 51: 7213-7216.

One effective strategy to improve the durability of  
electrocatalysts is to use one-dimensional (1D) Pt nanostructures, including nanowires (NWs),[8, 9] nanorods,[10,11] and  
nanotubes,[12, 13] owing to their inherent anisotropic morphology and unique structure compared to the isotropic 0D  
Pt NPs.[14–16] Meanwhile, the 1D Pt nanostructures have  
a unique combination of dimensions in multiple length  
scales, and they do not require a high surface-area support  
(e.g. carbon black). Thus, they have the potential to avoid the  
carbon-corrosion problem and further improve mass-transport characteristics.[13,17] 【！！3D纳米线的优势】

【！！3D纳米线的优势】

[38] B. Y. Xia, W. T. Ng, H. B. Wu, X. Wang, X. W. Lou, Self-supported interconnected Pt nanoassemblies as highly stable electrocatalysts for low-temperature fuel cells, Angewandte Chemie - International Edition, 2012, 51: 7213-7216.

Nevertheless, most of the reported  
1D Pt nanocatalysts are in the form of freestanding nanocrystals, which are similar to the Pt/CB catalyst.[18] Recently, assembly of 1D nanostructured Pt into two-dimensional (2D)  
membranes[18] and even three-dimensional (3D) nano-networks[19, 20] has attracted remarkable attention because of  
their many unique structural characteristics, including high  
porosity, good flexibility, large surface area per unit volume,  
and interconnected open-pore structures.[20, 21] Thus, the synthesis of controlled NW assembly would be an important new  
development, because each individual NW can be connected  
with a number of NWs in different ways to provide a large  
diversity of interconnectivity.[19, 22, 23] 【大量工作致力于阵列结构等】

【大量工作致力于阵列结构等】

[38] B. Y. Xia, W. T. Ng, H. B. Wu, X. Wang, X. W. Lou, Self-supported interconnected Pt nanoassemblies as highly stable electrocatalysts for low-temperature fuel cells, Angewandte Chemie - International Edition, 2012, 51: 7213-7216.

Consequently, the many  
efforts devoted to this area have led to 3D NW superstructures, such as arrays,[24–26] networks,[19] and hierarchical  
structures.[27]【发展直接合成3D纳米阵列是很大的挑战】

【发展直接合成3D纳米阵列是很大的挑战】

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Compared with template-assisted strategies for  
nanoassemblies,[19, 20, 28] however, it is significantly more challenging to develop a direct synthesis approach for 3D  
nanoassemblies.[29–31]【】  
 【本文，我们报道了pt纳米自组装结构的合成、表征、和电化学评估】

【本文，我们报道了pt纳米自组装结构的合成、表征、和电化学评估】

[38] B. Y. Xia, W. T. Ng, H. B. Wu, X. Wang, X. W. Lou, Self-supported interconnected Pt nanoassemblies as highly stable electrocatalysts for low-temperature fuel cells, Angewandte Chemie - International Edition, 2012, 51: 7213-7216.

Herein, we report the synthesis, characterization, and  
electrochemical evaluation of Pt nanoassemblies prepared by  
a one-pot method (see Supporting Information for the  
experimental details). 【本文，3Dpt纳米自组装结构，优势】

【本文，3Dpt纳米自组装结构，优势】

[38] B. Y. Xia, W. T. Ng, H. B. Wu, X. Wang, X. W. Lou, Self-supported interconnected Pt nanoassemblies as highly stable electrocatalysts for low-temperature fuel cells, Angewandte Chemie - International Edition, 2012, 51: 7213-7216.

We found that each Pt nanoassembly contained more than ten interconnected Pt NWs. This  
structure could maximize the surface area to volume ratio  
and therefore decrease the amount of catalytically inactive  
support material, while simultaneously minimizing the loading of the precious metal.[7, 32] Moreover, the interconnected  
3D nanoassemblies, consisting of long nanowires, make the Pt  
less vulnerable to dissolution, migration, Ostwald ripening,  
and aggregation compared to the 0D Pt nanoparticles.  
Furthermore, the mass transfer within the electrode can be  
facilitated by building 3D porous structures with the anisotropic, interconnected Pt NWs. 【本文，电化学活性】

【本文，电化学活性】

[38] B. Y. Xia, W. T. Ng, H. B. Wu, X. Wang, X. W. Lou, Self-supported interconnected Pt nanoassemblies as highly stable electrocatalysts for low-temperature fuel cells, Angewandte Chemie - International Edition, 2012, 51: 7213-7216.

Because of their many advantages, such 3D Pt-nanoassembly catalysts exhibit higher durability and activity than commercial electrocatalysts made of CB-supported 0D Pt nanoparticles. 【】

## [39] A. Ponrouch, S. Garbarino, E. Bertin, C. Andrei, G. A. Botton, D. Guay, Highly porous and preferentially oriented {100} platinum nanowires and thin films, Advanced Functional Materials, 2012, 22: 4172-4181.

1. Introduction  
【氨和水合肼电氧化研究很多年】

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[39] A. Ponrouch, S. Garbarino, E. Bertin, C. Andrei, G. A. Botton, D. Guay, Highly porous and preferentially oriented {100} platinum nanowires and thin films, Advanced Functional Materials, 2012, 22: 4172-4181.

The electrochemical oxidation of ammonia and hydrazine has  
been studied for many years. 【氨电氧化对水和空气分析传感器很重要】

【氨电氧化对水和空气分析传感器很重要】

[39] A. Ponrouch, S. Garbarino, E. Bertin, C. Andrei, G. A. Botton, D. Guay, Highly porous and preferentially oriented {100} platinum nanowires and thin films, Advanced Functional Materials, 2012, 22: 4172-4181.

This interest stems from the fact  
that ammonia oxidation is important in  
the fabrication of electrochemical sensors  
for water and air analyses. 【氨是污染物】

【氨是污染物】

[39] A. Ponrouch, S. Garbarino, E. Bertin, C. Andrei, G. A. Botton, D. Guay, Highly porous and preferentially oriented {100} platinum nanowires and thin films, Advanced Functional Materials, 2012, 22: 4172-4181.

In addition,  
ammonia is a common water pollutant  
in industrial wastewaters and in continental waters. 【氨电化学氧化转化成氮气在环境方面】

【氨电化学氧化转化成氮气在环境方面】

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Therefore, the development  
of an electrochemical method to convert  
ammonia into nitrogen would open up  
new possibilities in environmental electrochemistry. 【水合肼的应用】

【水合肼的应用】

[39] A. Ponrouch, S. Garbarino, E. Bertin, C. Andrei, G. A. Botton, D. Guay, Highly porous and preferentially oriented {100} platinum nanowires and thin films, Advanced Functional Materials, 2012, 22: 4172-4181.

Likewise, hydrazine is important in numerous industrial applications,  
including metal plating and protection  
against corrosion to control concentrations of dissolved oxygen. It is also used in  
various rocket fuels and as a component  
in explosives. Hydrazine is highly toxic  
and its electrochemical detection is also  
of significant interest. 【】 Finally, the most  
recent developments in low-temperature  
fuel cell technology have shown nitrogen  
hydrides, ammonia, and hydrazine to be  
suitable candidates in the race for commercial, high-performance, portable fuel  
cells.[1] 【大量研究致力于氨和水合肼电氧化】

【大量研究致力于氨和水合肼电氧化】

[39] A. Ponrouch, S. Garbarino, E. Bertin, C. Andrei, G. A. Botton, D. Guay, Highly porous and preferentially oriented {100} platinum nanowires and thin films, Advanced Functional Materials, 2012, 22: 4172-4181.

Several studies have been devoted to the  
electro-oxidation of ammonia and hydrazine on polycrystalline substrates. 【最近研究表明氨，水合肼具有结构敏感性】

【最近研究表明氨，水合肼具有结构敏感性】

[39] A. Ponrouch, S. Garbarino, E. Bertin, C. Andrei, G. A. Botton, D. Guay, Highly porous and preferentially oriented {100} platinum nanowires and thin films, Advanced Functional Materials, 2012, 22: 4172-4181.

More  
recently, studies of ammonia and hydrazine oxidation on single-crystal metal  
surfaces have been reported, providing  
evidence that the electro-oxidation process  
of these small nitrogen hydride molecules  
is structure-sensitive.[2–8] 【】 For example, in acidic solution, Nishihara et al[2] found that hydrazine adsorbs more readily on Pt  
(100) steps than on Pt (111) terraces. While Alvarez-Ruiz  
et al[4] showed that the basal planes of platinum and rhodium  
are much more active for hydrazine oxidation than the corresponding gold surfaces, they also showed that the (100) plane  
was one of the most active planes for all three metals. In alkaline media, the electrocatalytic activity of basal planes increases  
in the order Pt(110)Pt(100)Pt(111).[5] Likewise, in alkaline  
media, the electro-oxidation of ammonia on Pt occurs almost  
exclusively on surface sites with (100) symmetry.[6–8]  
Therefore, from a practical viewpoint, it would be highly  
desirable to prepare Pt electrodes that could exhibit both a  
high electrochemically active surface area and a preferentially-  
oriented {100} surface structure. In the early 1970s, several papers from Arvia’s group described an electrochemical

procedure to obtain Pt electrode surfaces with preferred orientations from bulk polycrystalline platinum. The procedure used  
to achieve this is based on the use of repetitive potential sweeps  
at high frequency under carefully-selected potential perturbation conditions.[9–11] Under the right conditions, the formation  
of preferentially-oriented {100} surfaces was achieved, but the  
roughness factor was low and does not exceed R3.[9] Under  
these conditions, while the intrinsic electrocatalytic activity  
(expressed as current per Pt surface atom) for the electrooxidation of nitrogen hydrides might be high, the overall electrocatalytic activity (expressed as current per geometric surface  
area) will remain low as a result of the low roughness factor.  
Several groups have focused on the use of preferentially-oriented {100} platinum particles to combine both a high  
intrinsic electrocatalytic activity and high electrochemically  
active surface area.[12] These particles consist of Pt cubic nanoparticles synthesized in the form of colloidal platinum, using  
a capping agent (sodium polyacrylate) and hydrogen gas as a  
reducing agent.[13] According to high-resolution transmission  
electron microscopy, these nanoparticles show fl at surfaces  
with {100} facets, and the distances between the adjacent lattice fringes is the interplanar distance of Pt {200}.[14] Pt nanoparticles prepared using the same method elsewhere have  
been shown to exhibit characteristic hydrogen adsorption/desorption peaks,[12,15–19] CO-stripping peaks,[15,17] as well as the  
characteristic response of irreversibly-adsorbed germanium on  
(100) sites of platinum.[18,19] These oriented nanoparticles show  
higher current densities for the electro-oxidation of ammonia  
in alkaline media than polycrystalline Pt nanoparticles.[12]  
Colloidal methods using organic ligand stabilizers are one of  
the most commonly used methods to make shape-controlled particles. However, the organic ligand shells can be diffi cult to remove.  
Various methods have been devised for cleaning the nanoparticles,  
such as heating in different atmospheres or submitting the nanoparticle to electrochemical decontamination by surface oxidation.  
However, these methods could produce a change in the surface  
structure. It was shown that modifi cation of the surface structure  
may be limited if electrochemical decontamination is performed  
under the right conditions, however, residual surfactant molecules  
were still present, causing an incomplete deposition of the Pt  
nanoparticles (fl oating) on the surface of the substrate.[20] From  
a more pragmatic point of view, the preparation of an electrode  
from an assembly of such nanoparticles is also challenging.  
 【电沉积优势，文献】

【电沉积优势，文献】

[39] A. Ponrouch, S. Garbarino, E. Bertin, C. Andrei, G. A. Botton, D. Guay, Highly porous and preferentially oriented {100} platinum nanowires and thin films, Advanced Functional Materials, 2012, 22: 4172-4181.

In contrast, electrochemical deposition is a fast, simple  
method which can produce three-dimensional particles directly  
attached onto a substrate or support. It is a one-step technique  
that requires no additional purification step, and its implementation is straightforward. It also has the added benefit of being  
applicable to substrates of different natures and geometric  
shapes. Moreover, it was shown recently that electrodeposition  
might be used to prepare metallic particles of various shapes.  
For example, it was demonstrated that granular Cr nanoparticles or hexagonal microrods could be obtained depending on  
the deposition conditions,[21] and the synthesis of tetrahexahedral Pd nanocrystals with high Miller Index facets was demonstrated using a pulse electrodeposition method.[22] Likewise, it  
was shown recently that Pt nanowire with preferentially-oriented  
{100} surfaces could be prepared through template-assisted  
deposition, using an anodic aluminum oxide membrane.[23]【】

【本文，制备了多孔Pt纳米线】

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In this study, highly porous Pt deposits in the form of thin  
films and nanowires were prepared with a large proportion of  
preferentially-oriented {100} surfaces. 【本文，系统研究了沉积参数对晶面比列的影响】

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A systematic study of the  
deposition conditions affecting the proportion of those preferentially-oriented {100} surfaces was conducted. 【】The benefits of  
using a porous Pt-based electrode with a large fraction of {100}  
surfaces are demonstrated by investigating the electro-oxidation  
of hydrazine in sulphuric acid and of ammonia in alkaline  
electrolyte.

## [40] Y. Tan, J. Fan, G. Chen, N. Zheng, Q. Xie, Au/Pt and Au/Pt 3Ni nanowires as self-supported electrocatalysts with high activity and durability for oxygen reduction, Chemical Communications, 2011, 47: 11624-11626.

【燃料，空气电池要求高活性催化剂】

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Electrochemical energy conversion devices, ranging from fuel  
cells to metal–air batteries, require effective electrocatalysts for  
the oxygen reduction reaction (ORR).1 【目前Pt/C存在的问题】

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[40] Y. Tan, J. Fan, G. Chen, N. Zheng, Q. Xie, Au/Pt and Au/Pt 3Ni nanowires as self-supported electrocatalysts with high activity and durability for oxygen reduction, Chemical Communications, 2011, 47: 11624-11626.

Currently, most popular ORR electrocatalysts consist of Pt nanoparticles physisorbed  
on carbon supports of high surface area. However, before such  
electrocatalysts are ideal for a wide range of practical applications, several critical issues must be addressed. (1) The ORR  
activity of these Pt nanocatalysts is relatively low owing to the  
inherently slow oxygen reduction kinetics. (2) Pt surface atoms  
suffer from serious dissolution and migration during the electrocatalytic process, resulting in aggregation of nanoparticles and  
deterioration of surface area and catalytic activity.2 (3) The  
serious carbon corrosion is also a critical problem with respect  
to the durability of catalysts.3  
 【】Recently, Pt-based hetero-nanostructures have shown enhanced  
electrocatalytic activity.4 For instance, Pt–Pd bimetallic nanodendrites exhibit much higher ORR activity than commercial Pt catalysts owing to the presence of highly active exposed  
facets.4a Also, the ORR activity of Pt catalysts can be much  
improved by incorporating other metal(s) to form an alloy  
with the proper composition and crystal phase.5 Pt3Ni is one  
of the most successful examples for such cases.5a–e The high  
ORR activity of Pt3Ni is attributed to the weaker OH adsorption arising from the decrease of the d-band center on the Pt  
skin formed by surface segregation.5a However, remarkable  
improvement has been achieved solely in electrocatalytic  
activity in most of the above studies. 【需要进一步提升高活性和高稳定性】

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For further evolution  
of the state-of-the-art Pt-based heterogeneous and alloy  
nanostructures, synthesis of nanocatalysts with both high  
activity and excellent durability is highly desirable and technologically important.6  
 【纳米线优势及特点】

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[40] Y. Tan, J. Fan, G. Chen, N. Zheng, Q. Xie, Au/Pt and Au/Pt 3Ni nanowires as self-supported electrocatalysts with high activity and durability for oxygen reduction, Chemical Communications, 2011, 47: 11624-11626.

One-dimensional (1-D) metal nanostructures have attracted  
particular attentions due to their excellent electrocatalytic  
performance.7 In general, the high conductivity of 1-D metal  
nanostructures due to the path directing effects of the structural anisotropy is conducive to the reaction kinetics on the  
catalyst surfaces.7a–d Moreover, 1-D metal nanostructures  
are less vulnerable to dissolution and aggregation than nanoparticles during the electrocatalytic process due to the millimetrescale length. 7e–h 【基体效应还不清楚】

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[40] Y. Tan, J. Fan, G. Chen, N. Zheng, Q. Xie, Au/Pt and Au/Pt 3Ni nanowires as self-supported electrocatalysts with high activity and durability for oxygen reduction, Chemical Communications, 2011, 47: 11624-11626.

Despite the fact that 1-D metal nanostructures  
have high conductivity and structural stability, the development  
of promising electrocatalysts by utilizing the support effect of  
1-D metal nanostructures has not been fully exploited.【】  
Considering that the incorporation of Au can suppress Pt  
dissolution and migration during ORR,1 c,6b the growth of Pt  
or Pt3Ni alloy on Au nanowires may integrate the advantages  
of Pt-based bimetallic catalysts with 1-D nanostructures to  
yield highly active and durable self-supported nanocatalysts.  
 【本文，纳米线被制备，表现出良好的活性和稳定性】

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[40] Y. Tan, J. Fan, G. Chen, N. Zheng, Q. Xie, Au/Pt and Au/Pt 3Ni nanowires as self-supported electrocatalysts with high activity and durability for oxygen reduction, Chemical Communications, 2011, 47: 11624-11626.

Herein, novel Au/Pt and Au/Pt3Ni nanowires consisting of Pt  
and Pt3Ni alloy nanodendrites grown on Au nanowires were  
synthesized, which exhibited much enhanced electrocatalytic  
activity and durability toward ORR when used as self-supported  
catalysts. 【本文，制备方法】

【本文，制备方法】

[40] Y. Tan, J. Fan, G. Chen, N. Zheng, Q. Xie, Au/Pt and Au/Pt 3Ni nanowires as self-supported electrocatalysts with high activity and durability for oxygen reduction, Chemical Communications, 2011, 47: 11624-11626.

In the first step, we prepared uniform Au nanowires following  
a reported methodology (Fig. S1, ESIw).8 These Au nanowires  
were then used as seeds for the formation of Au/Pt nanowires.  
【本文，形貌被SEM,TEM表征】

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[40] Y. Tan, J. Fan, G. Chen, N. Zheng, Q. Xie, Au/Pt and Au/Pt 3Ni nanowires as self-supported electrocatalysts with high activity and durability for oxygen reduction, Chemical Communications, 2011, 47: 11624-11626.

The morphologies of the prepared Au/Pt nanowires were  
examined by scanning electron microscopy (SEM) and transmission electron microscopy (TEM).【】 Typical SEM and TEM  
images reveal that a dense array of nanodendrites grow on the  
Au nanowires (Fig. 1a and b and S2a (ESIw)). Fig. 1d shows the  
high angle annular dark field scanning (HAADF-STEM) image  
and energy-dispersive X-ray (EDX) elemental mapping of Au  
and Pt, revealing the heterogeneous structure of the bimetallic  
nanowires, consisting of Au as the core and a dendritic Pt  
shell. The heterogeneous structure of the Au/Pt nanowires was  
also confirmed by X-ray diffraction (XRD). As shown in Fig. S3  
(ESIw), obvious Pt peaks can still be distinguished from the  
strong Au diffraction peaks though they are overlapped to some  
extent. The HRTEM image (Fig. 1c) indicates that the lattice  
spacing in the nanodendrites is 0.227 nm, consistent with the  
(111) lattice spacing of the face centered cubic (fcc) Pt.

## [41] C. M. Hung, Synthesis, structural and electrochemical characterization of honeycomb supported Pt-Pd-Rh composite catalyst for the decomposition of gaseous ammonia to nitrogen, in: Advanced Materials Research, 2011, pp. 21-25.

Introduction  
It is well known that ammonia (NH3) is a toxic, corrosive, highly reactive, and soluble alkaline  
inorganic gas with a pungent odor under ambient conditions, and is potentially harmful to human  
health as reported due to environmental concerns. Therefore, in an environmental point of view, the  
removal and control of NH3 emission from industrial waste streams are important in Taiwan. More  
recently, catalytic oxidation has been wildly proposed to enhance the effectiveness of advanced  
oxidation processes technology using dedicated catalysts, which potentially shorten the reaction times  
of oxidation, and allow it to proceed under milder operating conditions. Therein, the selective  
catalytic oxidation process of ammonia (NH3-SCO) in a stream to N2 and H2O is a promising  
approach for solving problems of NH3 pollution. At current, various catalysts have been used in  
oxidizing NH3 in the gaseous phase.  
Till now, cordierite, a crystalline magnesium aluminosilicate (2MgO-2Al2O3-5SiO2) with a  
hexagonal structure, combines a relatively low thermal expansion coefficient with thermal shock  
resistance and sufficient refractoriness has been reported [1]. As far as the previous systematic study  
[2] showed that platinum, palladium, and rhodium have marked activity and can be utilized to  
elucidate the reduction characteristics of NH3 conversion in a wet oxidation system. Additionally, the  
interaction between platinum, palladium and rhodium oxide is complex; that is various Pt-Pd-Rh  
interactions can result in synergistic effects that enhance their catalytic characteristics [3]. Therefore,  
the noble metals as additives in catalysts for enhancing NH3 conversion have been given great  
attention. Moreover, studying the redox state on catalyst material properties is important because this  
factor influences the catalytic properties. The previous works [4] showed that platinum, palladium,  
and rhodium metals exhibited remarkably activity used to elucidate the removal characteristics of  
NH3 conversion in a catalytic oxidation system.  
However, little work has been undertaken on the use of platinum-containing cordierite composite  
catalyst with cyclic voltammetric (CV) to determine the preliminary evaluation of the redox state of  
platinum-containing honeycomb cordierite composite catalyst. For these purpose, different  
techniques approach using OM and CV were employed to examine the behavior of  
platinum-containing honeycomb cordierite composite catalyst.

## [42] S. Sun, D. Yang, D. Villers, G. Zhang, E. Sacher, J. P. Dodelet, Template- And surfactant-free room temperature synthesis of self-assembled 3D Pt nanoflowers from single-crystal nanowires, Advanced Materials, 2008, 20: 571-574.

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Platinum has stimulated extensive research owing to its unusual physical and chemical properties. This has led to many  
technological applications, such as chemical sensors[1,2] and  
biosensors,[3] as catalysts in the production of hydrogen from  
methane[4] and in the reduction of pollutant gases emitted  
from automobiles[5] and, particularly, as electrocatalysts in  
polymer electrolyte membrane (PEM) fuel cells.[6,7] 【普遍认为活性和选择性依赖于尺寸形状】

【普遍认为活性和选择性依赖于尺寸形状】

[42] S. Sun, D. Yang, D. Villers, G. Zhang, E. Sacher, J. P. Dodelet, Template- And surfactant-free room temperature synthesis of self-assembled 3D Pt nanoflowers from single-crystal nanowires, Advanced Materials, 2008, 20: 571-574.

It is generally accepted that both catalytic efficiency and selectivity  
are highly dependent on the size and shape of the platinum  
material. 【】Therefore, the synthesis of platinum with specific  
nanostructure has become an area of considerable interest.[8–10]  
 【大多数研究受限于只能合成纳米颗粒】

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[42] S. Sun, D. Yang, D. Villers, G. Zhang, E. Sacher, J. P. Dodelet, Template- And surfactant-free room temperature synthesis of self-assembled 3D Pt nanoflowers from single-crystal nanowires, Advanced Materials, 2008, 20: 571-574.

To date, a range of techniques has been developed for preparing nanostructured platinum. Most of these studies have  
been limited to nanoparticles that could be obtained by using  
a variety of chemical procedures.[11–13] In general, such methods involve the reduction of platinum salts in the presence of  
organic surfactants or polymeric stabilizers at elevated temperature. The channels of porous materials,[14] self-assembled  
structures of surfactant,[15] as well as Se nanowires[16] have  
been used as templates to synthesize platinum nanowires or  
nanotubes. 【添加剂，模板法的缺点】

【添加剂，模板法的缺点】

[42] S. Sun, D. Yang, D. Villers, G. Zhang, E. Sacher, J. P. Dodelet, Template- And surfactant-free room temperature synthesis of self-assembled 3D Pt nanoflowers from single-crystal nanowires, Advanced Materials, 2008, 20: 571-574.

Template-based methods are technically complicated, owing to requirements for template removal to obtain  
pure products. This limits their applications, to some extent.[17] 【】  
Recently, Xia and co-workers have demonstrated the synthesis of single crystalline platinum nanowires by a polyol process, combined with the introduction of a trace amount of  
Fe2+ or Fe3+; poly(vinyl pyrrolidone) (PVP) was used as a surfactant, and the reaction was carried out at 110 °C.[18]【无模板，表面剂合成纳米线仍是挑战】

【无模板，表面剂合成纳米线仍是挑战】

[42] S. Sun, D. Yang, D. Villers, G. Zhang, E. Sacher, J. P. Dodelet, Template- And surfactant-free room temperature synthesis of self-assembled 3D Pt nanoflowers from single-crystal nanowires, Advanced Materials, 2008, 20: 571-574.

Despite  
this, the development of mild, template-free, surfactant-free  
routes for the production of single-crystalline platinum nanowires remains a challenge.  
 【本文，我们展示了3D花状结构大规模合成方法，无模板和添加剂。】

【本文，我们展示了3D花状结构大规模合成方法，无模板和添加剂。】

[42] S. Sun, D. Yang, D. Villers, G. Zhang, E. Sacher, J. P. Dodelet, Template- And surfactant-free room temperature synthesis of self-assembled 3D Pt nanoflowers from single-crystal nanowires, Advanced Materials, 2008, 20: 571-574.

Here, we demonstrate a facile, efficient, and economical  
route for the large-scale synthesis of 3D flower-like platinum nanostructures via a simple chemical reduction of hexachloroplatinic acid, commonly used for this purpose, with formic acid at room temperature, using neither template nor surfactant. 【】

Reduction took place by the following chemical reaction:  
H2PtCl6 + 2HCOOH →Pt + 6Cl– + 6H+ + 2CO2  
Briefly, H2PtCl6 is mixed with HCOOH in aqueous solution  
at room temperature and atmospheric pressure, and the mixture is then stored under the same conditions for periods up  
to 16 h, which permits Pt nanoflowers to form. The synthesized Pt nanoflowers consist of large quantities of single-crystal nanowires. Moreover, the nanoflowers could be assembled  
in situ onto carbon paper during the reduction process, and  
used as fuel cell charge-collecting electrodes. Assembly takes  
place through a self-organization process, without surface  
functionalization of the carbon support. Electrodes modified  
with these Pt nanoflowers exhibit good electrochemical activities, implying potential adoption in PEM fuel cells.

## [43] S. Sun, F. Jaouen, J. P. Dodelet, Controlled growth of Pt nanowires on carbon nanospheres and their enhanced performance as electrocatalysts in PEM fuel cells, Advanced Materials, 2008, 20: 3900-3904.

【pt尺寸、形状可控对提高活性很重要，以及pt应用】

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[43] S. Sun, F. Jaouen, J. P. Dodelet, Controlled growth of Pt nanowires on carbon nanospheres and their enhanced performance as electrocatalysts in PEM fuel cells, Advanced Materials, 2008, 20: 3900-3904.

Synthesis of platinum (Pt) nanostructures with controlled  
size and shape is one of the most important goals in developing  
highly active Pt catalysts for many industrial applications,  
including fine chemical synthesis,[1–4] gas sensing,[5] hydrogen  
production,[6] and the reduction of pollutant gases emitted  
from automobiles.[7] Pt is also the key catalyst in polymer  
electrolyte membrane (PEM) fuel cells:[8–10] it catalyzes  
hydrogen or alcohol oxidation at the anode and oxygen  
reduction at the cathode.[11,12] 【大量研究致力于pt纳米结构可控合成】

【大量研究致力于pt纳米结构可控合成】

[43] S. Sun, F. Jaouen, J. P. Dodelet, Controlled growth of Pt nanowires on carbon nanospheres and their enhanced performance as electrocatalysts in PEM fuel cells, Advanced Materials, 2008, 20: 3900-3904.

A great deal of effort has been  
devoted to the chemical synthesis of Pt nanostructures. 【以前的工作仅限于纳米粒子的合成，而且这些制备方法使用有机活性剂和稳定剂】

【以前的工作仅限于纳米粒子的合成，而且这些制备方法使用有机活性剂和稳定剂】

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Most of  
the previous work, however, has been limited to nanoparticles  
that could be obtained by using a variety of chemical  
procedures.[13–15] In general, such methods involve the  
reduction of Pt salts in the presence of organic surfactants  
or polymeric stabilizers at elevated temperature. 【纳米线优势】

【纳米线优势】

[43] S. Sun, F. Jaouen, J. P. Dodelet, Controlled growth of Pt nanowires on carbon nanospheres and their enhanced performance as electrocatalysts in PEM fuel cells, Advanced Materials, 2008, 20: 3900-3904.

In contrast to  
nanoparticles, one-dimensional (1-D) structures such as  
nanowires exhibit additional advantages associated with their  
anisotropy, unique structure, or surface properties.[16,17]  
 【纳米线的合成方法，文献】

【纳米线的合成方法，文献】

[43] S. Sun, F. Jaouen, J. P. Dodelet, Controlled growth of Pt nanowires on carbon nanospheres and their enhanced performance as electrocatalysts in PEM fuel cells, Advanced Materials, 2008, 20: 3900-3904.

Polycrystalline Pt nanowires and nanotubes have been  
synthesized by templating against channels in porous materials,[18–21] self-assembled structures of surfactant,[22] and Ag or  
Se nanowires.[23] Recently, Xia and coworkers have demonstrated the synthesis of single crystalline Pt nanowires by a  
polyol process, combined with the introduction of a trace  
amount of an iron species (Fe2 þ or Fe3 þ); poly(vinyl  
pyrrolidone) was used as a surfactant, and the reaction was  
carried out at 110 8C.[24] 【无添加剂合成纳米线仍是很大的挑战】

【无添加剂合成纳米线仍是很大的挑战】

[43] S. Sun, F. Jaouen, J. P. Dodelet, Controlled growth of Pt nanowires on carbon nanospheres and their enhanced performance as electrocatalysts in PEM fuel cells, Advanced Materials, 2008, 20: 3900-3904.

It remains a grand challenge to  
synthesize single crystalline Pt nanowires via a surfactant-free,  
mild chemical route. 【】  
It is widely recognized that the biggest concern in fuel cells is  
to improve the performance of the Pt on the cathode, where  
oxygen molecules are reduced into water.[25–27] Pt nanoparticles are often employed in fuel cells and related applications.  
 【尽管取得很大进展，但是高活性和利用率的Pt远微不足道】

【尽管取得很大进展，但是高活性和利用率的Pt远微不足道】

[43] S. Sun, F. Jaouen, J. P. Dodelet, Controlled growth of Pt nanowires on carbon nanospheres and their enhanced performance as electrocatalysts in PEM fuel cells, Advanced Materials, 2008, 20: 3900-3904.

Despite the progress made in the past, production of Pt catalyst  
with great catalytic performance and utilization efficiency is  
still costly and far from being trivial. 【本文，我们报道了液相合成纳米线方法。】

【本文，我们报道了液相合成纳米线方法。】

[43] S. Sun, F. Jaouen, J. P. Dodelet, Controlled growth of Pt nanowires on carbon nanospheres and their enhanced performance as electrocatalysts in PEM fuel cells, Advanced Materials, 2008, 20: 3900-3904.

Here we report a simple  
room temperature aqueous phase synthesis of single-crystal  
nanowires of Pt on the nanospheres of a carbon black, and  
study their catalytic activity for the oxygen reduction reaction  
(ORR) in PEM fuel cells. 【本文，发展了无模板和添加剂的纳米线合成方法】

【本文，发展了无模板和添加剂的纳米线合成方法】

[43] S. Sun, F. Jaouen, J. P. Dodelet, Controlled growth of Pt nanowires on carbon nanospheres and their enhanced performance as electrocatalysts in PEM fuel cells, Advanced Materials, 2008, 20: 3900-3904.

We have developed a facile wetchemical procedure to synthesize unsupported single-crystal Pt  
nanowires and their flower-like assembly via the reduction of  
hexachloroplatinic acid (H2PtCl6) by formic acid (HCOOH) at  
room temperature, without surfactant or template.[28] Further  
syntheses revealed that, by simply adding a certain amount of  
carbon black in the aqueous solution of H2PtCl6 and HCOOH,  
large quantities of Pt nanowires can be directly grown, within  
72 h at room temperature, on the nanospheres of the carbon  
support. In these nanostructures, the high-surface-area carbon  
black (Vulcan XC72, specific area 213 m2 g 1), a commonly  
used catalyst support in fuel cells, serves as the core, and the  
electrocatalytically active Pt nanowires are grown radially  
from the surface of the carbon particles. 【本文，电化学活性】

【本文，电化学活性】

[43] S. Sun, F. Jaouen, J. P. Dodelet, Controlled growth of Pt nanowires on carbon nanospheres and their enhanced performance as electrocatalysts in PEM fuel cells, Advanced Materials, 2008, 20: 3900-3904.

We demonstrate that  
such Pt nanowire/C nanocomposites show enhanced catalytic  
activity for the ORR compared with a state-of-the-art Pt/C  
catalyst made of Pt nanoparticles. 【】

## [44] E. P. Lee, J. Chen, Y. Yin, C. T. Campbell, Y. Xia, Pd-catalyzed growth of Pt nanoparticles or nanowires as dense coatings on polymeric and ceramic participate supports, Advanced Materials, 2006, 18: 3271-3274.

This Communication describes an approach that can control the growth of Pt into shells that consist of nanoparticles  
or nanowires on colloidal spheres. Core/shell particles have  
been extensively studied largely because of their attractive  
properties (optical, mechanical, magnetic, or catalytic) that  
are often different from their bulk counterparts.[1] As a result  
of their unique features, core/shell particles hold promise in  
potential applications such as controlled delivery, catalysis,  
magnetic information storage, optical sensing, and confinement of reactions.[2] Many research efforts have been directed  
towards the development of new techniques for “engineering”  
such materials with well-controlled properties.【性能可以通过成分、维度、结构等调控】

【性能可以通过成分、维度、结构等调控】

[44] E. P. Lee, J. Chen, Y. Yin, C. T. Campbell, Y. Xia, Pd-catalyzed growth of Pt nanoparticles or nanowires as dense coatings on polymeric and ceramic participate supports, Advanced Materials, 2006, 18: 3271-3274.

In general, the  
properties of core/shell particles can be tailored precisely by  
varying the composition, dimension, and structure of the cores  
or shells.[1]【纳米线受到关注，但是对于低成本、高效的制备工艺的研究还很难欠缺】

【纳米线受到关注，但是对于低成本、高效的制备工艺的研究还很难欠缺】

[44] E. P. Lee, J. Chen, Y. Yin, C. T. Campbell, Y. Xia, Pd-catalyzed growth of Pt nanoparticles or nanowires as dense coatings on polymeric and ceramic participate supports, Advanced Materials, 2006, 18: 3271-3274.

One-dimensional (1D) nanostructures, especially  
nanowires, have attracted much attention due to their potential use as interconnects in fabricating electronic devices.[3]  
However, with respect to the procedure and cost effectiveness, producing nanowires is far from being trivial. 【发展简单的纳米线制备方法仍然是面临挑战】

【发展简单的纳米线制备方法仍然是面临挑战】

[44] E. P. Lee, J. Chen, Y. Yin, C. T. Campbell, Y. Xia, Pd-catalyzed growth of Pt nanoparticles or nanowires as dense coatings on polymeric and ceramic participate supports, Advanced Materials, 2006, 18: 3271-3274.

It remains  
a grand challenge to develop a plausible method for generating large quantities of nanowires from various metals.[4] 【本文，发展了可拓展行的纳米线制备方法】

【本文，发展了可拓展行的纳米线制备方法】

[44] E. P. Lee, J. Chen, Y. Yin, C. T. Campbell, Y. Xia, Pd-catalyzed growth of Pt nanoparticles or nanowires as dense coatings on polymeric and ceramic participate supports, Advanced Materials, 2006, 18: 3271-3274.

Here  
we present a versatile approach capable of generating core/  
shell particles, with the cores being polymer or silica beads  
and the shells being dense, uniform coatings of Pt nanoparticles or quasiradial Pt nanowires. 【】  
We recently discovered that the introduction of a trace  
amount of iron species (Fe3+ or Fe2+) to the polyol process  
could induce the formation of Pt nanowires[5a] or multipods[5b]  
by significantly reducing the net reduction rate of the salt precursor. We have also shown that these nanowires could be catalytically activated to grow from the surface of micrometersized aggregates consisting of Pt nanoparticles.[6] Herein, we  
demonstrate a more affordable and practical method for  
growing Pt nanowires by using Pd-coated colloidal spheres to  
imitate the catalytic property of the Pt aggregates. Moreover,  
this procedure can be modified to grow thick, uniform shells  
composed of Pt nanoparticles. The key to the success of these  
syntheses are Pd nanoparticles (2–4 nm in size) that can be  
readily generated in situ as sub-monolayers on colloidal  
spheres terminated by an amino functional group by reducing  
a palladium precursor with ethanol under sonication.[7] No  
growth of Pt nanoparticles or nanowires was observed when  
there were no Pd nanoparticles on the surface of the colloidal  
spheres. We note that such Pd nanoparticles have been widely  
used as a catalyst in the electroless deposition of thin films of  
metals such as Ni, Cu, and Ag on various substrates.[8] In the  
present work, Pt nanowires with aspect ratios of up to 30  
could be controllably grown through an iron-mediated polyol  
reduction when there was a catalytic metal exposed on the  
substrate surface. Furthermore, shells of Pt nanoparticles with  
thicknesses of up to 100 nm could be formed by reducing the  
amount of iron species added to the reaction solution.

## [45] Li, T., et al. (2012). "Electrocatalytic properties of hollow coral-like platinum mesocrystals." ACS Applied Materials and Interfaces 4(12): 6942-6948.

1. INTRODUCTION  
    【Pt是优秀的催化剂，被广泛应用】
2. 【Pt是优秀的催化剂，被广泛应用】
3. [45] Li, T., et al. (2012). "Electrocatalytic properties of hollow coral-like platinum mesocrystals." ACS Applied Materials and Interfaces 4(12): 6942-6948.
4. Platinum nanomaterials are excellent catalysts for a number of reactions, including the industrial synthesis of nitric acid,  
   reduction of pollutant gases, oil cracking, proton exchange  
   membrane (PEM) fuel cells, etc.1 【目前Pt催化剂基本由小纳米颗粒构成，大面积，多晶结构，提高活性】
5. 【目前Pt催化剂基本由小纳米颗粒构成，大面积，多晶结构，提高活性】
6. [45] Li, T., et al. (2012). "Electrocatalytic properties of hollow coral-like platinum mesocrystals." ACS Applied Materials and Interfaces 4(12): 6942-6948.
7. At present, the most widely  
   used Pt catalyst consists of small nanoparticles (2 −5 nm) that  
   have a large surface area or large polyhedral structures with  
   high-index facets to enhance surface reaction activity.2,3 【Pt颗粒问题】
8. 【Pt颗粒问题】
9. [45] Li, T., et al. (2012). "Electrocatalytic properties of hollow coral-like platinum mesocrystals." ACS Applied Materials and Interfaces 4(12): 6942-6948.
10. The  
    main problem associated with the supported Pt nanoparticle  
    catalysts is the significant loss of electrochemical surface area  
    (ECSA) and, thus, the degradation of catalytic performance  
    caused by Pt nanoparticle migration, coalescence, or even  
    detachment from the catalyst system. In addition, Ostwald  
    ripening of the Pt nanoparticles could occur because of their  
    high surface energy and zero-dimensional structural features.4  
     【挑战：同时实现高活性和稳定性】
11. 【挑战：同时实现高活性和稳定性】
12. [45] Li, T., et al. (2012). "Electrocatalytic properties of hollow coral-like platinum mesocrystals." ACS Applied Materials and Interfaces 4(12): 6942-6948.
13. Therefore, our main challenge is the simultaneous realization of  
    highly active and highly durable catalyst.  
     【提高稳定性的策略：合金化，维度调控】
14. 【提高稳定性的策略：合金化，维度调控】
15. [45] Li, T., et al. (2012). "Electrocatalytic properties of hollow coral-like platinum mesocrystals." ACS Applied Materials and Interfaces 4(12): 6942-6948.
16. Several strategies for improving the durability of Pt-based  
    catalysts against the loss of ECSA have been developed,  
    including alloying protocols such as Pt −Pd, Pt −Au, Pt −Ni, Pt −  
    Co, and Pt −Fe and various structures such as one-dimensional  
    Pt nanostructures, two-dimensional macroscopic membranes,  
    and three-dimensional nanostructures.5 −12 【介孔提高了稳定性，原因及影响因素，文献】
17. 【介孔提高了稳定性，原因及影响因素，文献】
18. [45] Li, T., et al. (2012). "Electrocatalytic properties of hollow coral-like platinum mesocrystals." ACS Applied Materials and Interfaces 4(12): 6942-6948.
19. In this paper, the  
    application of mesostructures for improving the durability of a  
    catalyst will be highlighted. This proposal partially results from  
    the fact that mesocrystals demonstrate some intrinsic  
    advantages such as a rough surface, a high internal porosity,  
    the small size of the building block, a single-crystal structure,  
    and high densities of crystalline defects,13 −16 which all may  
    contribute to high activity.17 Furthermore, some previous  
    studies have also implied that mesostructures with single-crystal  
    features have a promising stability in an electrochemical  
    reaction. This is because the larger porous mesoparticles with  
    a single-crystal structure are more stable than small nanoparticles during the electrochemical reaction.5 For example, Qi  
    et al. reported unique spindle-shaped nanoporous anatase TiO2  
    mesocrystals. Because of their intrinsic single-crystal-like nature,  
    as well as the high porosity of the nanoporous mesostructures,  
    the products exhibited remarkable crystalline-phase stability  
    and improved performance as anode materials for lithium ion  
    batteries.18 In addition, Zheng et al. synthesized mesocrystalline  
    Pd nanocorolla via a surface-confined etching growth process.  
    Because of the presence of internal voids and an increased  
    apparent thickness, the Pd mesocrystals also demonstrated  
    several features superior to the single-domain Pd nanosheets.19【】  
    In previous studies, nanoparticle-aggregated nanostructures  
    for use as electrocatalysts, e.g., Pd −Pt bimetallic nanodendrities, as reported by Xia and other groups, were much  
    more active than the state-of-the-art Pt/C catalyst because of  
    their relatively large surface areas.5,20 −22 【颗粒太大导致活性面积损失】
20. 【颗粒太大导致活性面积损失】
21. [45] Li, T., et al. (2012). "Electrocatalytic properties of hollow coral-like platinum mesocrystals." ACS Applied Materials and Interfaces 4(12): 6942-6948.
22. However, the  
    durability could still be improved because of the presence of  
    nanostructures with a size of ∼50 nm resulting in the reduction  
    of ECSA loss. 【如果在微观尺度设计结构，将增大活性面积，同时提高活性和稳定性，文献】
23. 【如果在微观尺度设计结构，将增大活性面积，同时提高活性和稳定性，文献】
24. [45] Li, T., et al. (2012). "Electrocatalytic properties of hollow coral-like platinum mesocrystals." ACS Applied Materials and Interfaces 4(12): 6942-6948.
25. If one can design a structure at the meso- or  
    macroscale that demonstrates a large surface area and  
    simultaneously high electrochemical activity, then durability  
    would probably be achieved. Recently, well-controlled mesoporous single-crystal Pt has been synthesized using a hard template strategy; however, the catalytic properties have not  
    been studied.23【本文，在以前经验的基础上，我们报道了中空珊瑚状的介孔Pt，具有高性能】
26. 【本文，在以前经验的基础上，我们报道了中空珊瑚状的介孔Pt，具有高性能】
27. [45] Li, T., et al. (2012). "Electrocatalytic properties of hollow coral-like platinum mesocrystals." ACS Applied Materials and Interfaces 4(12): 6942-6948.
28. In this paper, on the basis of our previous  
    experience in synthesizing a variety of hierarchically structured
29. mesocrystals,24−28 we report a new type of hollow coral-like  
    mesostructural Pt catalyst with simultaneously high electrochemical activity and improved durability. The Pt mesocrystals  
    were synthesized via a facile replacement process with  
    hierarchically structured Ag nanoparticles as the template.  
     【本文，介孔形貌和性能被研究】
30. 【本文，介孔形貌和性能被研究】
31. [45] Li, T., et al. (2012). "Electrocatalytic properties of hollow coral-like platinum mesocrystals." ACS Applied Materials and Interfaces 4(12): 6942-6948.
32. The microstructures of hollow coral-like Pt mesocrystals and  
    their electrocatalytic properties toward methanol oxidation  
    were investigated in detail.【本文，珊瑚状介孔Pt的结构特点及性能】
33. 【本文，珊瑚状介孔Pt的结构特点及性能】
34. [45] Li, T., et al. (2012). "Electrocatalytic properties of hollow coral-like platinum mesocrystals." ACS Applied Materials and Interfaces 4(12): 6942-6948.
35. The obtained Pt mesocrystals  
    possess unique structural features, such as a hollow interior and  
    a porous nature; thus, they exhibit remarkable electrocatalytic  
    activity. Importantly, the single-crystal-like structure of the Pt  
    mesocrystals, which consists of a great number of nanoparticle  
    building units ( ∼5 nm), results in them demonstrating an  
    improved durability during electrochemical oxidation of  
    methanol. 【】Additionally, this synthetic protocol will also be  
    employed to obtain various components, such as Pd- and Ptbased alloy catalysts.  
    2. EXPERIMENTAL SECTION