Innovation and Performance Optimization Research of Key Components and Application of Hydrogen Fuel Cells

Guanqun Ma [1,*], Tianyu Shen [2], Yichen Shu [3], Jingle Xin [4]

[1] Chang'an Dublin International College of Transportation, Chang'an University, Xi'an, 710018, China

[2] School of Energy and Power Engineering, University of Shanghai for Science and Technology, Shanghai, 200093, China

[3] Shenghuazizhu academy, Shanghai, 201600, China

[4] School of Mechanical Engineering, University of Shanghai for Science and Technology, Shanghai, 200093, China

* Corresponding Author Email: guanqun.ma@ucdconnect.ie

Abstract. Hydrogen fuel cells have gained significant attention due to their environmentally friendly, clean, and efficient characteristics. While there has been extensive research on hydrogen fuel cells, widespread adoption has not yet been achieved. There is ample room for further development. This paper presents a comprehensive review of proton exchange membranes, catalysts, electrode structures, materials, and the potential applications of hydrogen fuel cells. Novel doping technologies and material applications are gradually maturing to enhance the adaptability of proton exchange membranes. Various methods are being explored to improve the performance of platinum-based catalysts and other precious metal catalysts. Non-precious metal alternatives have been developing to reduce costs. Optimization of existing electrode materials and transition layers is underway. Research into new materials is taken to enhance the efficiency and stability of hydrogen fuel cells. Hydrogen fuel cells are Currently employed in vehicles and ships and may continue to find application in maritime and aerospace sectors in the future.

Keywords: Hydrogen fuel cell, Proton exchange membrane, Catalyst, Electrode material.

1. Introduction

Nowadays, new energy technologies, led by batteries, are developing rapidly. Among the various types of batteries, hydrogen fuel cells, as an emerging technology, have a broad development prospect. Compared with the current widely used lithium batteries, hydrogen reserves are more abundant than lithium, providing a prerequisite for the mass production of hydrogen fuel cells. And the reaction emissions only water, so hydrogen fuel is a clean energy, in line with the concept of sustainable development, which also makes the hydrogen fuel cell has broad prospects for development. Currently, the consumption of fossil fuels is the main source of carbon dioxide emissions, and several traditional mechanical cycles (Brayton cycle, Otto cycle) are relatively inefficient due to the loss of energy. Hydrogen fuel cell (HFC) can be considered as an advanced technology with higher efficiency and cleaner emissions. Compared to conventional power generation systems, hydrogen fuel cells have efficiencies as high as 40-85%, compared to only about 35% for diesel generator sets and 29-42% for turbine generators. Hydrogen has the highest specific energy of all common fuels, which is three times greater than diesel and liquefied natural gas (about 120 MJ/kg) [1]. Therefore for the development of battery technology, hydrogen fuel cell is considered as one of the key development directions.

The efficiency of hydrogen fuel cell is closely related to the proton exchange membrane, catalyst type, and electrode material selection. The proton exchange membrane will be ruptured by mechanical, chemical and thermal decay during cell operation, resulting in lower efficiency. The size of the adsorption capacity and the anti-poisoning ability of the catalyst affect the reaction rate, which reduces the efficiency of the cell. In addition, the electrode materials need to have certain stability and good conductivity to ensure that the reaction continues to be stable. In this paper, based on

hydrogen fuel cell, some research review work on performance enhancement is carried out. Firstly, the structure and principle of hydrogen fuel cell are reviewed, and the innovation and performance optimization of key components of hydrogen fuel cell are explored from three aspects: catalyst, proton exchange membrane and electrode materials. And based on this, we discuss the application of hydrogen fuel cells, improve the efficiency of hydrogen fuel cells, and provide a development direction for future hydrogen fuel cells.

2. Performance Optimization of Proton Exchange Membrane in Hydrogen Fuel Cells

2.1. The Working Principle of Fuel Cells Work

Hydrogen fuel cell is an energy supply device that is able to convert the chemical energy possessed by hydrogen and oxygen into electrical energy, which can be regarded as the reverse reaction of water electrolysis, and its main reaction is shown in formula (1).

$$H_2(g) + 0.5O_2(g) \rightarrow H_2O + \text{energy (electrical power + heat)} \quad (1)$$

The working principle of the hydrogen fuel cell is shown in Fig. 1 [1].

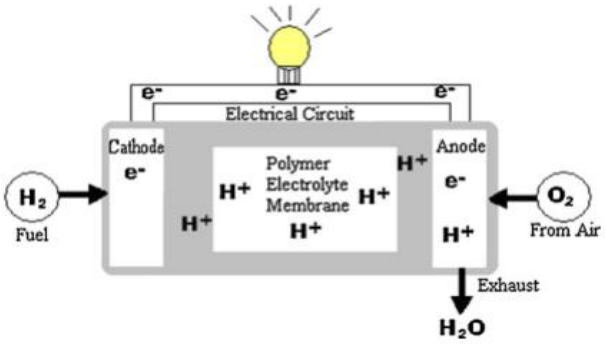


Figure 1. Schematic diagram of hydrogen fuel cell operation [1]

The catalyst oxidizes hydrogen at the anode and converts it into electrons and protons while combining with the oxygen protons at cathode to produce H_2O. The transfer of electrons from anode towards cathode through an external circuit also generates electricity.

Proton exchange membrane is a thin film structure situated at membrane electrode inside of the hydrogen fuel cell, which assumes function of providing a channel for the migration and transportation of protons. The proton exchange membrane comprises an anode, a cathode and a catalytic layer. Hydrogen is supplied to the anode waiting for oxidation reaction while oxygen is supplied to the cathode preparing for reduction reaction. The oxidation reaction involves hydrogen to produce protons and electrons, which return to the cathode respectively and combine with oxygen to produce water. During this process, electrons traverse external circuit and form current and protons penetrate the proton exchange membrane from the anode towards the cathode. As a critical component of hydrogen fuel cell, material selection and structure design of proton exchange membrane will have a noteworthy influence on general performance of the hydrogen fuel cell.

2.2. Materials Optimization of Proton Exchange Membrane

The performance of proton exchange membrane can be affected by a multitude of environmental factors, including humidity and temperature. Most of proton exchange membranes utilized in hydrogen fuel cells at present are composed of perfluorinated polymer materials. However, due to the relatively high cost of traditional perfluorinated polymer materials and the potential leads to fluorine contamination, the application of this material is relatively limited. Therefore, it is imperative to find new type of materials that could offer enhanced efficiency and versatility to fabricate proton exchange membranes.

F. Xu and colleagues' research have demonstrated that proton exchange membranes made from fluorene-based polymers that possess favorable solubility exhibit superior mechanical properties, dimensional stability, oxidative stability and performance that are comparable to current materials [2]. This type of membrane has potential to serve as an alternative to perfluorinated polymer materials. As demonstrated by E. Qu and colleagues' research, phosphoric acid-doped polybenzimidazole proton-conducting membranes display the characteristics that enhancing the electrical conductivity of proton exchange membranes while simultaneously possess robust mechanical stability [3]. Wessam Nimir and colleagues' have demonstrated that adding heteropolyacids in the preparation of composite proton exchange membranes will significantly increase electrical conductivity at high temperature environments and reduce the occurrence of fuel crossover phenomena [4]. It is believed that it will effectively improve the efficiency of hydrogen fuel cells working at high temperature environments when appropriate immobilization techniques in polymer matrices are developed. Hongying Tang and colleagues have demonstrated that phosphoric acid-doped intrinsic ultramicroporous membranes exhibit a broader adaptability of operational temperatures and humidities, along with raised phosphoric acid retention in high-humidity environments and enhanced proton conductivity compared with conventional high-density phosphoric acid-doped proton exchange membranes [5]. Zhu Liyu and colleagues' research demonstrated that the modification of Nafion membranes will result in increased mechanical stability and durability [6]. It is believed that composite membranes comprising poly (vinyl alcohol) (PVA) will display superior self-healing capabilities, which enables them to recover proton conductivity after minor damage.

2.3. Structure Optimization of Proton Exchange Membrane

The conversion efficiency of proton exchange membrane is not solely contingent on their material properties, it is also determined by structural characteristics of membranes. Different proton exchange membrane structures are varied in hydrogen conversion efficiencies. Therefore, the focus of fuel cell technology research is the structure optimization of proton exchange membrane. Currently, proton exchange membranes are generally available in three structural configurations: parallel, crossing and serpentine. According to Jiazhou Lu and colleagues, serpentine flow field is the most effective structure, parallel flow field is the least effective and the crossing structure occupies the intermediate position. Although there is a large voltage decrease in the serpentine flow field, the distribution of the catalytic layer with hydrogen at anodic and the concentration distribution of water at cathodic are excellent [7]. However, Li Bing and colleagues' research showed that performance with appropriate aperture metal foam flow field has better efficiency than that of traditional serpentine flow field under specific conditions [8]. The hydrogen fuel cell with aperture of 580 μm metal foam flow field has the best performance at the humidification temperature of 50°C and then operating temperature of 30°C, with a 25.1% increase in the maximum current density and a 21.2% increase in the maximum power density compared with the serpentine flow field. Therefore, different structures under different conditions have different effects on the conversion performance of the proton exchange membrane. The research conducted by Jishi Xiong and colleagues reveals that the optimal runner depth is 0.4 when the performance significantly enhanced, and the width of the fuel cell bank need to be equal or less than the runner width [9]. When the runner scale is 1:1:1, 1:2:2, 1:3:1, 1:3:2, there is no significant difference in performance. In conclusion, proton exchange membrane structure plays an important role in proton exchange membrane fuel cells. It can imply proton conduction and gas separation effectively, thus realizing efficient conversion of fuel into electricity and promoting the development of sustainable energy. The optimization and improvement of proton exchange membrane structure will definitely further promote the progress of hydrogen fuel cell technology.

3. Optimization of Catalyst Performance for Hydrogen Fuel Cells

3.1. Catalysis Mechanism

When a hydrogen fuel cell operates, hydrogen gas is ionized at the anode to form hydrogen ions, while oxygen undergoes reduction at the cathode to become oxygen anions. The combination of oxygen at the cathode and hydrogen ions generates water. However, the ionization rate of hydrogen gas is faster than breaking the covalent bond in oxygen, making the rate of the oxygen reduction reaction crucial in determining the overall reaction process. A catalyst can be introduced at the cathode to increase total reaction surface area and reduce reaction activation energy. This accelerates the process of oxygen reduction and enhances the efficiency of hydrogen fuel cells.

3.2. Precious Metal Catalyst

3.2.1 Advantages of Pt as catalyst

Catalysts commonly utilize precious metals as their primary component, such as Pt, Pd, Au, Ru, Ir, and Ag. These precious metals exhibit significant catalytic activity. Due to their scarcity, they are quite expensive. The adsorption of oxygen molecules or atoms on the catalyst's surface is essential for promoting the oxygen reduction reaction. Therefore, the adsorption strength of the catalyst is crucial in this process. It should neither be too strong nor too weak. Otherwise, it may lead to difficulties in removing oxygen atoms or initiating the reaction. As depicted in Fig.2, platinum demonstrates the best oxygen reduction activity among different metals [10].

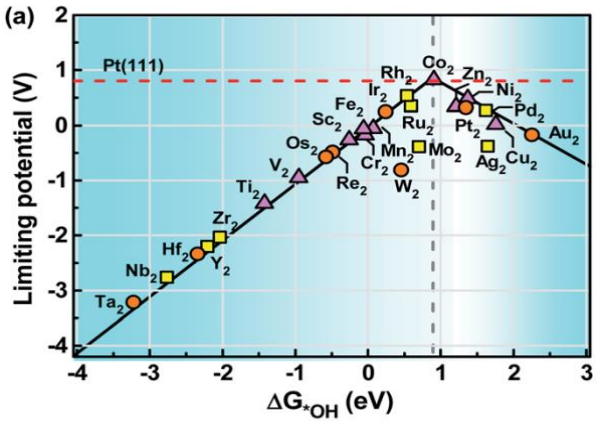


Figure 2. The adsorption and reduction of oxygen on different metals [10]

Consequently, most currently used catalysts are Pt-based and widely applied due to this superior performance.

3.2.2 Pt/C catalysts

Chen Qisheng employed different methods to prepare Pt/C catalysts under various operating conditions and discovered that annealing temperature, preparation method, Pt loading, and grinding method can impact the performance of Pt/C catalysts [11].

High-temperature annealing was found to decrease catalytic performance. Regardless of the method used, the post-annealing electrical current was consistently lower than the current generated without annealing. Elevated temperature may lead to crystal enlargement, reducing the specific surface area of the catalytic powder and reducing its performance. Three distinct methods—mechanical chemical method, ethanol mechanical chemical method, and ethanol impregnation stirring method—were utilized for preparing Pt/C catalysts. Among these methods, it was observed that both the ethanol mechanical method and ethanol impregnation stirring method exhibited comparable performances while the mechanical chemical approach outperformed both. In terms of the mechanical chemical approach, it was noted that the performance of the prepared catalyst showed a positive correlation with the amount of Pt used. Greater amounts of Pt resulted in improved catalyst performance. However, once a certain threshold of Pt usage was reached, further increases did not

significantly enhance catalytic performance. Therefore, selecting an appropriate amount of Pt should involve a comprehensive consideration encompassing material cost and catalyst effectiveness. Compared to agate grinding, expanded ball milling demonstrated superior electrocatalytic performance. It is suitable for widespread application in expanded ball milling processes.

3.2.3 Pt-base alloy catalyst

Based on the Pt/C catalyst, both PtCo/C and PtCoMn/C catalysts exhibit better catalytic activity and stability. The combination of inexpensive metals with platinum reduces the platinum content and thus lower the cost. Comparative studies of different catalysts have revealed that multi-component catalysts outperform binary ones, addressing some of the issues associated with Pt-based catalysts while simultaneously reducing costs [12].

Currently, perfluorosulfonic membranes are commonly used in hydrogen fuel cells. At the cathode, H_2O_2 is generated during the oxygen reduction reaction. Transition metals are unstable in acidic environments and react with H^+. The generated metal ions react with H_2O_2 to produce strong oxidizing radicals (·OH, ·OOH). Perfluorosulfonic acid will be decomposed by these radicals, causing partial detachment of the catalyst and thereby decreasing the stability of the membrane electrode or causing membrane electrode penetration.

In comparison to other metals, Mn^{2+} is less prone to undergo the Fenton reaction. Therefore, Mn as the second component in Pt-based alloy catalysts can lead to greater stability of the membrane electrode. Mn-based catalysts also exhibit superior electrocatalytic activity. However, their preparation is challenging due to the low oxygen reduction potential of Mn. The introduction of Mn into Pt-based catalysts can mitigate membrane electrode corrosion and enhance catalyst performance.

Fan Hanqing prepared PtMn/C catalysts using different components and found through membrane electrode testing and accelerated aging tests that the stability of the PtMn/C catalyst was approximately equivalent to that of the platinum carbon catalyst [13]. This suggests that the PtMn/C catalyst has minimal impact on the stability of the membrane electrode. Additionally, it was demonstrated that, low-particle-size platinum carbon catalysts are required to improve the performance of PtCoMn/C catalysts through sodium borohydride and formaldehyde methods at varying heat treatment temperatures.

3.2.4 Other Precious metal catalysts

Replacement of platinum with other Precious metals as catalysts. The catalytic effect of gold-cobalt alloys prepared by reversed-phase microemulsion method was investigated for its action on the anode of borohydride-hydrogen peroxide fuel cell (DBHFC). The results showed that the direct oxidation activity of loaded Au - Co alloy catalysts for BH_4 was higher than that of pure Au nanocatalysts, among which the $Au_{45}Co_{55}$/C catalysts showed the highest catalytic activity. Using $Au_{45}Co_{55}$/C as DBHFC anode electrocatalyst, the catalytic activity reached 66.5 mW cm^{-2} when the discharge ampere density was 85mAcm^{-2} and 25°C which is shown in Fig.3 [14].

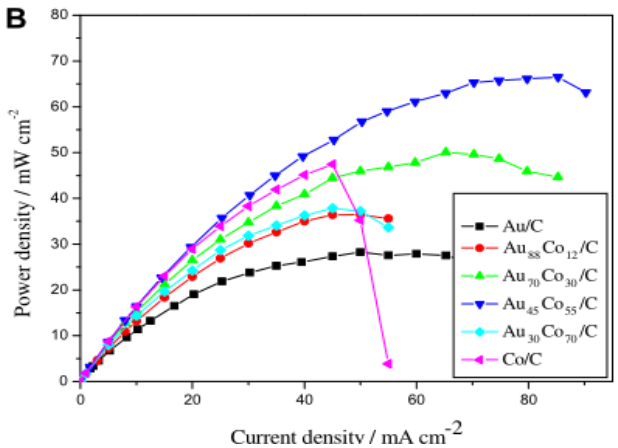


Figure 3. Catalytic activity of Au45Co55/C catalysts [14]

Well-defined tungsten-doped palladium nanocubes were prepared by using palladium nanocubes as seeds with adjustable atomic percentages of tungsten ranging from 0% to 1.5%. One of the best performing 1.2% W-doped Pd nanocubes/C catalysts obtained had a much-improved electrocatalytic performance for the oxygen reduction reaction in alkaline media, with a 4.7-fold increase in specific activity and a 2.5-fold increase in mass activity as compared to that of the commercial platinum-based catalysts, with specific mass exchange ampere densities of up to 1.18 mA cm_{pd}^{-2} and 0.25 A mg_{pd}^{-1} at 0.9 V_{RHE} which is shown in Fig.4 [15].

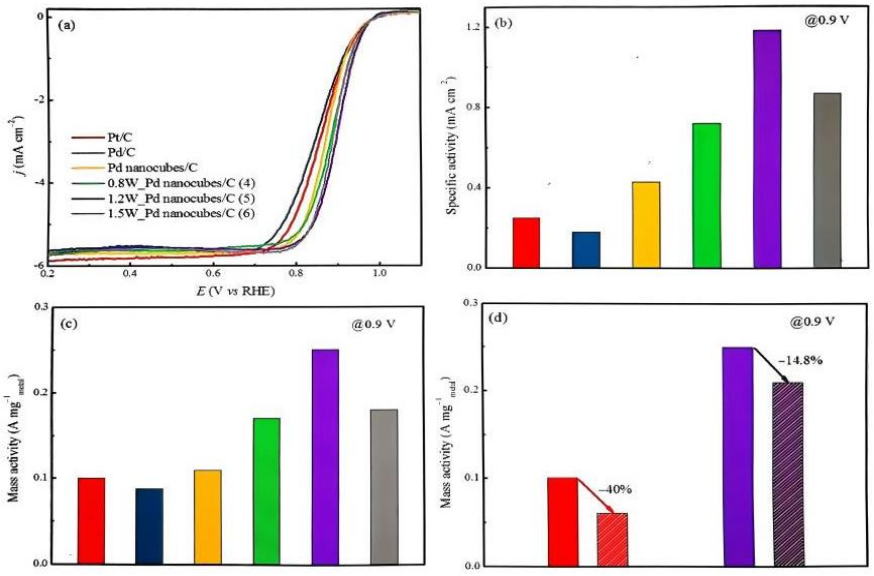


Figure 4. Properties of 1.2%W-doped Pd nanocubes/C catalyst [15]

These two solutions avoid the use of platinum-based alloys as catalysts and to some extent solve the problems of reduced activity and corrosion of the material. However, the use of other precious metals (e.g., gold, palladium, etc.) is still significant. This does not solve the problem of high cost of ownership.

3.3. Non-precious Metal Catalysts

Although noble metal catalysts have good catalytic activity for redox reactions in fuel cells, highly loaded platinum-based catalysts are usually required in fuel cells to mitigate the activity reduction caused by adsorption on the catalyst surface. This leads to problems such as high cost of their use, reduced activity, and corrosion by electrolytes. In order to solve these problems, research on innovation and performance optimization of non-precious metal catalysts has been put on the agenda.

3.3.1 Nickel-based catalysts

For the cathodic oxygen reduction reaction (ORR) in alkaline-exchange membrane fuel cells, non-precious metal catalysts that are less expensive and perform similarly to platinum-based catalysts have currently been developed; however, nickel-based catalysts are the only non-precious metal catalysts that show the greatest promise for the anodic hydroxidation reaction (HOR). By forging amorphous nickel boride (NiB/C) loaded on XC-72, boron-doped nickel (B-Ni/C) was produced. The specific mass exchange ampere densities of B-Ni/C at 50 mV were 0.035 mA cm_{Ni}^{-2} and 27.95 mA mg_{Ni}^{-1} which is shown in Fig.5, respectively, indicating a ten-fold increase in mass activity relative to the undoped catalyst [16].

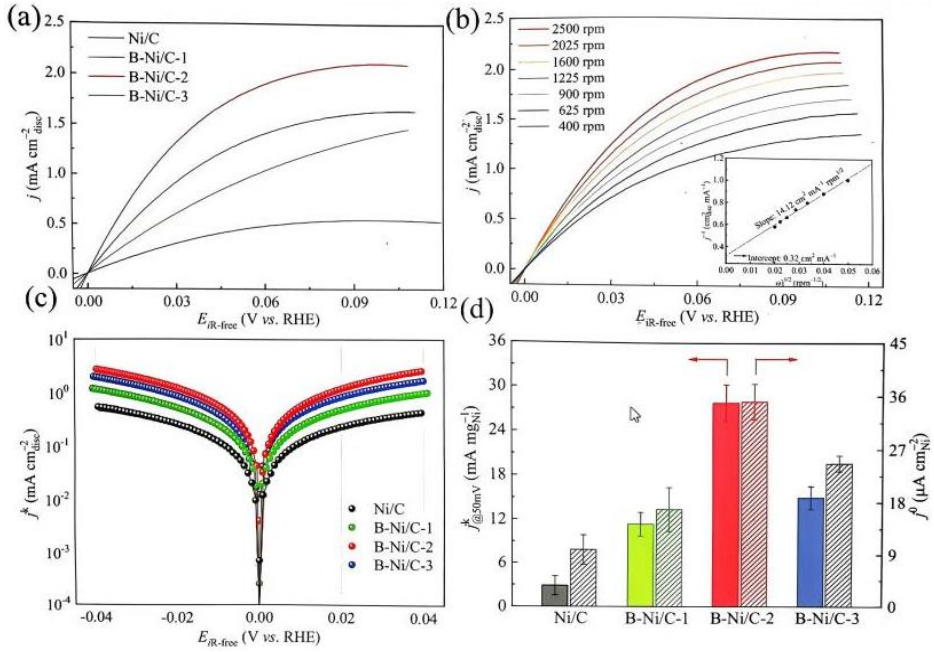


Figure 5. Boron-doped nickel (B-Ni/C) mass exchange current density [16]

Their activities were evaluated in KOH. Long-term testing in H_2 with a concentration of 1 in 10,000 CO showed only a minor decrease of activity in comparison to platinum-based catalysts [16]. Nickel hydroxyl oxide electrocatalysts uniformly doped with copper, created via in situ electrochemical reconstruction. Copper increases the hydroxyl nickel oxide's conductivity and encourages the synthesis of high-valent nickel, both of which improve electrocatalytic efficacy. At 1.72 V_{RHE}, the ampere density reached 227 $mA \cdot cm^{-2}$ which is shown in Fig.6, After using 32H, it maintained 73% of its initial activity, demonstrating a high level of stability [17].

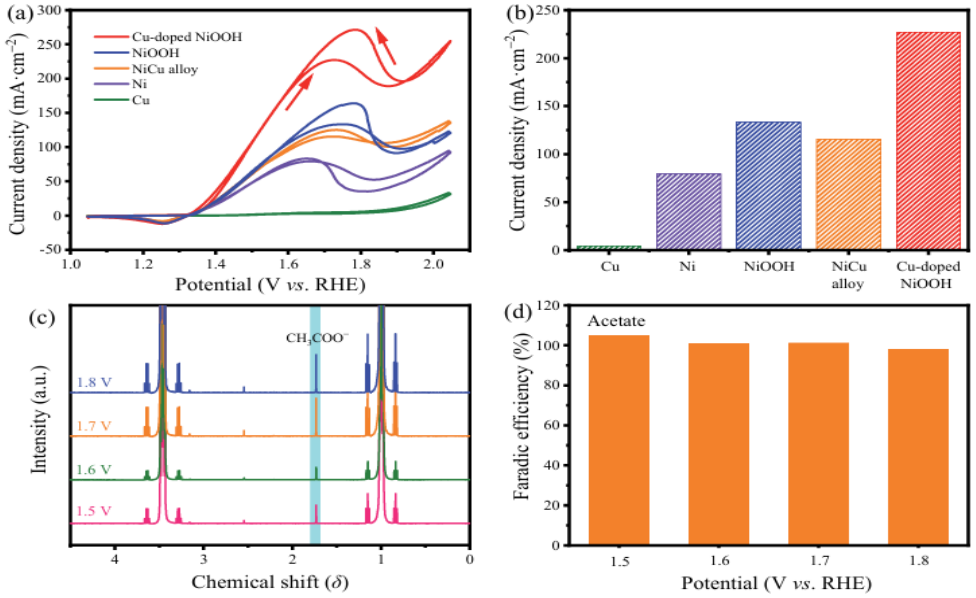


Figure 6. Current density of uniformly doped nickel hydroxyl oxide electrocatalysts [17]

3.3.2 Metal-Nitrogen-Carbon (M-N-C) structured catalysts

Another approach is to substitute precious metal catalysts with metal-nitrogen-carbon (M-N-C) structured catalysts; Fe-N-C and Mn-N-C catalysts are two examples of such catalysts. By heat treating KJ600 carbon black with poly-2-aminobenzimidazole and $FeCl_3$ as the capping materials, two catalysts, Fe-N-C-ABI and Fe-N-C-PmPDA, were produced. The Fe-N-C-ABI catalyst demonstrated a 0.92 V initial reduction potential and a 9.21 A/g mass current density at a potential of 0.8 V in 0.1 mol/L H_2SO_4 solution; in comparison, the Fe-N-C-PmPDA catalyst displayed similar

onset potentials but a higher catalytic activity with a 13.4 A/g mass ampere density which is shown in Fig.7 [18].

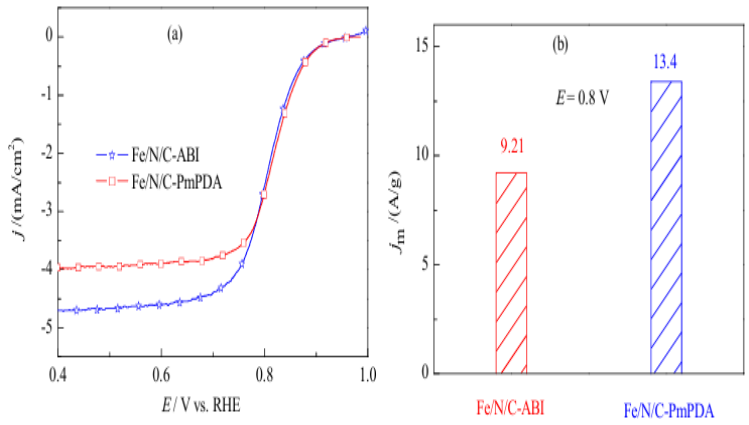


Figure 7. Mass current density of Fe-N-C catalysts [18]

Using manganese phthalocyanine (MnPc) as a precursor, the catalytic effect of Mn-N-C/G-30 nanocatalysts for oxygen reduction by the organometallic vapor deposition process was even better than that of existing commercial platinum-based catalysts. Compared with commercial Pt-based catalysts, Mn-N-C/G-30 has a higher onset potential (0.97 V), and a higher oxygen reduction ampere density (1.4 mA/cm^2) at a potential of 0.88 V which is shown in Fig.8, resulting in a more efficient catalytic effect [19].

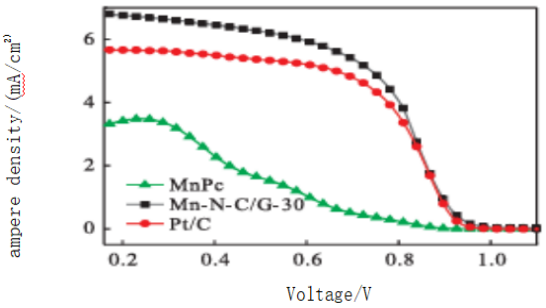


Figure 8. Oxygen reduction current density of manganese-nitrogen-carbon catalysts [19]

4. Electrode Optimization of Hydrogen Fuel Cells

4.1. Basic Structure of Electrode

Electrodes are fundamental component of hydrogen fuel cells. Represent the area in which the reaction gas is separated, radiation and reaction products discharged, the electrodes must meet specific requirements regarding high electrical conductivity, good thermal conductivity and considerable durability. The selection of materials and the structure design usually have a significant impact on the comprehensive performance of hydrogen fuel cells. Hydrogen fuel cell electrodes are highly integrated and primarily comprised of pole plates and diffusion layers. Pole plates are generally classified into three main categories: graphite, metal and composite material, which are based on materials used in the construction. The gas diffusion layer is comprised of a microporous layer and a support layer, which offer the functions of current conduction, radiation and product management. Therefore, specifically optimization of electrodes and diffusion layer will significantly improve the general performance of hydrogen fuel cells.

4.2. Materials of Electrode Plates

Electrode plates in the hydrogen fuel cells also known as flow field plates. Among these types of plates, the graphite plate has reached a relatively stable level of maturity. Though the strength of graphite plate is comparatively lower, it has proved to possess excellent electrical conductivity and

corrosion resistance. The metal plate is widely known for its superior electrical conductivity and thermal conductivity. However, its corrosion resistance is inferior. The more prevalent approach is to cover the surface of the electrode plates with corrosion-resistant materials, usually including precious metals, diamonds and metal compounds. Additionally, researching and developing new composite material plates is a potential way for consideration. Composite plates are basically composed of thermoplastic resin polymers, thermosetting resins and electric conductive fillers. It is anticipated that the application of graphite covering to the surface of metal matrix composite plates will significantly enhance the corrosion resistance while simultaneously reducing costs.

4.3. Improvement of Electrode Materials

Materials for electrodes based on graphene The phonon and electrical properties of graphene are changed when hydrogen atoms are loaded onto it, resulting in hydrogenated graphene. Compared to single-layer graphene, multilayer graphene is better suited for hydrogenation. Sp^3 C-H bonds are created when hydrogen atoms are loaded onto the basal surface of monolayer graphene. On graphene, hydrogen can be adsorbed by chemisorption—a process that involves chemical bonding, such as ionic or covalent bonding with carbon atoms—or physical adsorption, which uses weak van der Waals forces [20].

Creation of innovative molybdate materials for solid oxide batteries' anodes with varying molybdenum valences. Characterizations included the physical phase, stability, microstructure, and conductivity. An electrode with a simplified design was used to investigate the electrochemical activity of H2 oxidation. Certain materials exhibit unique phenomena whereby, when exposed to operating conditions (in some reducing atmospheres), they break down into multiple phases and form new nanostructured surfaces. These new phases and surface features then improve electrocatalytic activity and electronic conductivity. The best molybdates have polarization resistances that are two orders of magnitude lower than doped strontium titanate. Cathodic polarization considerably activates a large number of molybdate materials, which operate better under cathodic (electrolytic) polarization than under anodic (fuel cell) polarization [21].

4.4. Transition Layer Material

In hydrogen fuel cells, commonly used solid oxide fuel cells often operate at high temperatures (700°C or above), which can lead to performance issues. Chemical reactions between the electrodes and electrolyte form an insulating layer, reducing the battery's conductivity and efficiency. To address this challenge, a key transition layer material is placed between the electrode and electrolyte, typically samarium-doped ceria (SDC). However, this material forms an insulating substance with yttria-stabilized zirconia (YSZ) at temperatures exceeding 1300°C, posing certain challenges for its use in YSZ-based batteries.

At 1500°C, SDC undergoes sintering, so reducing the sintering temperature of SDC to below 1300°C can resolve this issue. Liu Rui discovered in his study that doping Bi into SDC can effectively lower its sintering temperature and prevent the formation of an insulating layer [22]. After doping 7% Bi into SDC, the sintering temperature can be reduced to 1200°C and the overall reaction will not be impacted. Compared to pure SDC, applying this transition layer at temperatures above 700°C leads to superior electrical performance.

5. Hydrogen Fuel Cells Applications

5.1. Overview of the Current Status of Hydrogen Fuel Cells Applications

Hydrogen fuel cells and other batteries of same type are used frequently in many fields. It plays a big role in transportation and logistics drones and other fields. According to the author Pengran Gao, large-scale technological development is carried out in many regions [23]. And the country has set up many policies to support the breakthrough of hydrogen fuel technology. The market interest in hydrogen fuel cells is gradually increasing with the introduction of the market. However, safety

accidents at individual energy storage and power generation facilities and pure electric vehicles have cast doubt on the security arrangement of hydrogen fuel cells. However, the concentration of hydrogen in the air is 4.0V% to 75.0V% (volume percentage), the explosion occurred in the range of 18.3V% to 59.0V%, the density of hydrogen is the smallest of all gases in the air, and the volatility of hydrogen is very strong cannot take a long time to completely evaporate. There is no doubt about the safety of hydrogen fuel cells. Hydrogen fuel cells are used in many applications because they have a high degree of safety and energy efficiency with fewer emissions.

5.2. Hydrogen Fuel Cells in New Energy Vehicles

Hydrogen fuel cell is a power generation device that directly converts the chemical energy of hydrogen and oxygen into electrical energy, and it is for the opposite reaction of electrolysis of water. These batteries have multiple advantages, including high efficiency, environmental protection, safety and reliability, and are particularly suitable for commercial vehicles, such as medium and heavy trucks, logistics trucks, refrigerated trucks and city buses. Hydrogen fuel cells have significant advantages over conventional batteries. Author Pengran Gao writes that modern gasoline cars are much less safe and innovative than hydrogen fuel cells [23]. And with air pollution increasing nowadays, the promotion of hydrogen fuel cells is a feasible and very efficient proposal. Promote economic development while protecting the environment. And he also mentioned that lithium batteries are suitable for intra-city logistics work and transportation work belonging to short-distance operation, while hydrogen batteries are suitable for long-distance transportation. It is true that hydrogen fuel cells have significant and outstanding advantages for transportation.

5.3. Hydrogen Fuel Cells in Ships

The application range of hydrogen fuel cells is gradually expanding, with outstanding performance in the field of automotive power, while the exploration of applications in emerging segments such as marine cruise ships is also increasing. According to an article written by Yulong Feng, in 2008, the Alsterwasser, a fuel cell-propelled ship from the German Zemships project, was in operation on the river Alster, the world's first fuel cell-electric-propelled passenger ship in operation [24]. And in 2009, the Norwegian Fellowship program has successfully installed MCFC fuel cells on the Viking Lady, an offshore supply vessel operating in the North Sea, which is the world's first operational vessel to conduct onboard power generation tests with fuel cell technology. China's first fuel cell yacht was the Fuyuan 1 developed by Beijing Fuyuan Fuel Cell Company in September 2002. 2005 Shanghai Maritime University developed the fuel cell-powered Tianxiang 1 test vessel, which has a battery power of 2kW and can sail for about 3 hours, with a design speed of about 7km/h, and an actual speed of about 7 knots, which can be used for tourism, transportation, etc. The vessel has a battery power of 2kW and can sail continuously for about 3 hours, with a design speed of about 7km/h, and an actual speed of about 7 knots, which can be used for tourism and transportation.

6. Conclusion

Hydrogen fuel cells have unique advantages over other battery forms because of higher energy density for the same amount of energy storage. Hydrogen reserves are more abundant and the emission of this reaction is only water, so hydrogen fuel is a clean energy, in line with the concept of sustainable development. At present, it is believed that the improvement of the performance of hydrogen fuel cell can be started from its proton exchange membrane, electrode, catalyst and other aspects.

In the material selection and structure design part, it is believed that cutting-edge research on new alternative materials has gained some progress, and the new doping technology and material applications are gradually maturing. In the future, more advanced proton exchange membrane is expected to further improve the electrical conductivity and be adapted to wider range of temperatures

and humidity to enhance the performance of hydrogen fuel cells, which will provide a prerequisite for the wide application of hydrogen fuel cells.

In the catalyst part, the type of material selected has a great influence on the performance of the battery. Currently, the commonly used precious metal catalysts are mainly platinum-based catalysts. In the preparation of platinum catalysts, the annealing temperature should be below 900℃. Using mechanochemical method and expanded ball milling and increasing the platinum loading can lead to a better performance of catalysts. Adding Mn to the catalyst can avoid the generation of Fenton reaction and thus prevent perfluorinated sulfur film. In addition to Pt-based catalysts, there are other precious metal catalysts such as gold and palladium. Among them, the gold-cobalt alloy catalyst was concluded that its direct oxidation activity was higher than that of pure Au nano-catalysts, with the highest catalytic activity of $Au_{45}Co_{55}$/C catalyst. Another tungsten-doped Pd nanocube catalyst showed the best catalytic performance when tungsten atoms reached 1.2%. Although these two catalysts solved the problems of reduced activity of platinum-based catalysts and corrosion of materials, the excessive cost put the research of non-precious metal catalysts on the agenda. Boron-doped nickel tested for activity showed a 10-fold increase in mass activity over the undoped catalysts. And it is relatively difficult to reduce activity. The copper homogeneously doped nickel hydroxyl oxide electrocatalysts are more active due to the high nickel production, and very stable. Another solution is the use of metal-nitrogen-carbon structured catalysts, as exemplified by two catalysts, iron-nitrogen-carbon, and manganese-nitrogen-carbon. The two forms of Fe-N-C catalysts have a higher onset reduction potential, and similar onset potential with higher catalytic activity. the Mn-N-C/G-30 nanocatalysts have even more efficient catalytic effects compared to the existing Pt-based catalysts.

In the electrode part, current goal is to optimize the electrode plate and diffusion layer to obtain comprehensive performance improvement. There is still room for development of electrode plate materials, which can further reduce the cost while improving the durability and stability. The use of graphene-based electrode materials and new molybdate materials will improve electrocatalytic activity and electronic conductivity, which will guarantee the performance and efficiency of batteries.

Hydrogen fuel cell technology is now maturing, and the next step is to utilize it appropriately and efficiently. In the future, research may focus on the use of hydrogen battery cars and long-distance transportation. It may also be applied in the direction of navigation and aerospace. There are already several successful cases, and we believe that there will be a breakthrough in the future.

Authors Contribution

All the authors contributed equally and their names were listed in alphabetical order.

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