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Research on the development and application of the hydrogen energy

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Abstract. In recent years, global warming has been an ongoing concern for experts, and the cause of this problem is the over-reliance on fossil fuels, so finding a new source of energy that can replace traditional fossil fuels is essential at this stage. In terms of hydrogen production, solar hydrolysis is a promising method for converting sunlight into renewable, sustainable, and green hydrogen energy. The most representative pathway for converting solar radiation into molecular hydrogen is photovoltaic chemistry (PEC). In terms of hydrogen storage, researchers have identified the potential of a new type of hydrogen storage vessel, the "hybrid hydrogen storage vessel," which combines an aluminum-carbon fiber reinforced plastic (Al-CFRP) composite vessel with a hydrogen storage alloy. An evaluation of this system has shown that the hybrid hydrogen storage vessel has advantages over conventional hydrogen storage technologies in terms of volume and weight of stored hydrogen. In terms of hydrogen applications, hydrogen-fueled electric powertrains offer a solution for long-distance driving using clean energy, whereas battery-powered vehicles are plagued by range limitations, which is a shortcoming in hydrogen applications. This paper critically examines the potential of hydrogen as a sustainable energy source and presents three aspects of hydrogen technology, respectively its production, storage and application. This essay highlights the importance of chemical engineering principles in optimizing the production, storage and utilization of hydrogen energy for a clean, sustainable energy future.

Keywords: hydrogen production, hybrid hydrogen storage vessel, hydrogen applications, photovoltaic chemistry.

1. Introduction

In recent years, the growing concern about global warming has necessitated the urgent search for alternative energy sources to supplant the traditional fossil fuels that have been identified as significant contributors. Hydrogen is one alternative that has garnered significant attention. Hydrogen's potential as a sustainable, renewable, and pure energy source suggests that it will play a crucial role in combating the negative effects of climate change and ensuring energy security. The present investigation seeks to offer a comprehensive analysis of the potential of hydrogen as a viable alternative energy source through the assessment of three key facets of hydrogen technology: its production, storage, and utilization. This paper will focus on the solar hydrolysis method, specifically the application of photovoltaic chemistry (PEC), as a sustainable approach to hydrogen production [1]. According to Takeichi, furthermore, this study aims to examine the advancements in hydrogen storage, with specific emphasis on the 'hybrid hydrogen storage vessel [2]. This innovative technology combines the benefits of solid and high-pressure hydrogen storage to form a solid, high-pressure hybrid hydrogen storage tank. The present study aims to address the constraints associated with traditional storage techniques in relation to their capacity and mass. Moreover, this paper will examine the various applications of hydrogen as a means to power electric powertrains, serving as a potential remedy for the range constraints encountered by battery-operated vehicles, which is especially relevant in the context of extended journeys. This paper seeks to explore the potential of hydrogen in shaping a future centered on clean and sustainable energy, employing an analysis rooted in the principles of chemical engineering.

2. The limitation and improvement of the hydrogen energy production

2.1. Limitation

This paragraph describes how to produce hydrogen efficiently using solar energy. Researchers from the City University of Hong Kong (CityU) and King Abdullah University of Science and Technology have joined hands and successfully developed a novel photoelectrochemical system [3]. Photoelectron chemical reaction (PEC) is one of the methods to produce hydrogen in an environmentally friendly way by using solar energy combined with semiconductor materials as catalysts to decompose water into oxygen and hydrogen. However, due to technological limitations, the efficiency of solar energy in converting hydrogen is generally very low, coupled with unstable performance and high cost, photoelectron chemical systems have not been widely used. Traditional photoelectron chemical system semiconductor is easy to be corroded, in the many used as a water decomposition of photoelectron chemical materials, three-five semiconductors (III-V semiconductors) is the most attention, especially InGaP (indium gallium phosphide) and GaAs (gallium arsenide). These two compounds have excellent photophysical properties, but the disadvantage is that their performance is not stable. In the process of water decomposition, there will be a chemical reaction and corrosion, thus causing the system to fail rapidly. At present, almost all photoelectron chemical systems made of silicon and semiconductors are based on the traditional single-side element structure, i.e., all the major elements, including the light-absorbing layer, the surface protection layer, and the catalyst, are assembled on one side of the photoelectron chemical device, while the back side is mostly used as the circuit connection. This creates problems, as the surface protection layer and catalyst are on top of the light absorbing layer, the light reflection caused by both of them significantly hinders the absorption of light and leads to a decrease in photocurrent during the water decomposition process, and some of the photons are lost as they pass through the GaAs substrate. This is a major reason why photoelectron chemical systems have not been popularized.

2.2. Improvement

In response to these shortcomings of existing photoelectron chemical systems, researchers from the City University of Hong Kong (CityU) and King Abdullah University of Science and Technology spent more than three years designing a new system that not only resolves the contradiction of surface protection and catalysts hindering light absorption, but also reduces cost and improves system stability, and significantly improves the efficiency of solar energy conversion to hydrogen [3]. The innovation of the design is to reorganize the positions of the light-absorbing layer, the catalyst and the protective layer, so that the catalyst layer, which was originally placed on the top surface, is now placed at the bottom of the new system, which can reflect any unabsorbed long-wavelength photons, thus increasing the device's absorption of long-wavelength photons. The new design also incorporates an anti-reflective layer to reduce surface reflections and improve light utilisation. The results of the study show that the application of the newly developed photoelectron chemical system in an alkaline electrolyte dramatically increases the efficiency of solar hydrogen production from the typical 3% to about 9%, with the highest stability of any system of its kind: a maximum of more than 150 hours as we can see in Figure 1. In contrast, the semiconductor devices in most similar systems fail within minutes, and longer ones last only a few hours [3].

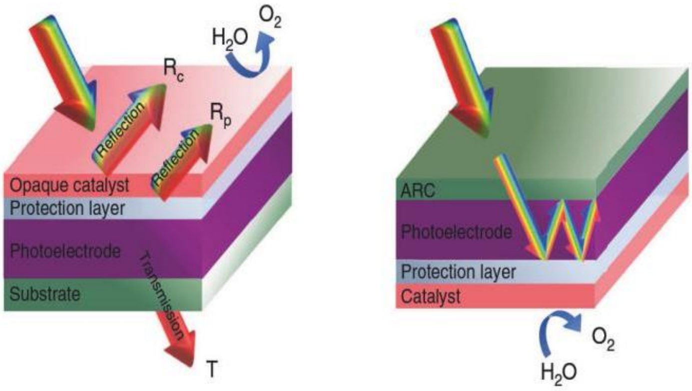

Figure 1. Rearrange the light-absorbing and the electrocatalyst layers. a: the conventional device design. b: the novel device design.

3. The limitation and improvement of the hydrogen energy storage

3.1. Limitation

This paragraph explains the technology in the area of hydrogen energy storage and relates, in particular, to a solid high-pressure hybrid hydrogen storage tank based on solid hydrogen storage and high-pressure hydrogen storage. According to the research, for low-temperature liquid hydrogen storage, it has a high volumetric hydrogen density of about 70 kg/m^3, but there is a problem of evaporation of liquid hydrogen, thus requiring a high level of adiabatic properties of the tanks, in addition to the high energy consumption of refrigeration required to achieve the required low temperatures, thus limiting its application [4]. For high-pressure gaseous hydrogen storage, its filling and discharge rate is very fast, but its volumetric hydrogen storage density is relatively low, by increasing the hydrogen pressure can increase the bulk density of hydrogen, but the increase is limited, at room temperature, even if the hydrogen pressure is increased to 70 MPa, the bulk density of hydrogen is only about 40 kg/m^3. Solid-state hydrogen storage using hydrogen storage materials (e.g., metal hydride) is deposited into the closed container of hydrogen storage materials. The use of hydrogen storage materials to achieve the solid-state storage of hydrogen has a high bulk density of hydrogen storage, even higher than the bulk density of liquid hydrogen. For example, LaNi5 hydrogen storage alloys have a bulk density of hydrogen storage that can reach more than 100 kg/m^3, but the process of absorbing and discharging the hydrogen is limited by the limitations of heat transfer.

3.2. Improvement

However, the hydrogen absorption and discharge process is limited by heat transfer, which makes the filling and discharge rate of the solid state hydrogen storage device slower. Combining solid-state hydrogen storage with high-pressure gaseous hydrogen storage to form a solid-state, high-pressure hybrid hydrogen storage can make full use of the advantages of these two types of hydrogen storage, i.e., it has a fast charging and discharging rate, and at the same time, the volumetric hydrogen storage density can be greatly increased on the basis of high-pressure gaseous hydrogen storage. Another significant advantage of solid-state, high-pressure hybrid hydrogen storage is that the high-pressure portion of the hydrogen storage accounts for the majority of the hydrogen, which significantly improves the ability to sustain the hydrogen supply. Therefore, solid-state high-pressure hybrid hydrogen storage has a very good application prospect.

4. The limitation and improvement of the hydrogen energy application

4.1. Limitation

This paragraph describes some of the shortcomings of hydrogen energy in its applications and suggests a better solution. According to Yue et al. hydrogen re-electrification is the use of hydrogen to generate electricity [5]. Hydrogen can first be re-electrified by combustion. Similar to internal combustion engines using petrol, some internal combustion engines or turbines can use hydrogen directly. However, due to the relatively low volumetric energy density of hydrogen, hydrogen internal combustion engines are less efficient than gasoline internal combustion engines, with thermodynamic efficiencies of about 20-25%, and this is a shortcoming of using hydrogen as a power system, with the most representative problem being the limited sailing range. In addition, when combusting hydrogen, no carbon dioxide is emitted, but nitrogen oxides are.

4.2. Improvement

The use of fuel cells is a desirable way to maximize the potential benefits of hydrogen compared to hydrogen combustion engines, as fuel cells convert the chemical energy of hydrogen directly into electrical energy, and therefore can be 60-80% efficient, with only water as a by-product. This solves the problem of limited range and has no environmental impact. Fuel cells are now used commercially in a variety of stationary and transport applications.

5. Conclusion

In summary, advancements in photoelectron chemical systems, solid-state high-pressure hybrid hydrogen storage technology, and hydrogen reelectrochemical technology have significantly contributed to the progress and enhancement of hydrogen energy applications. These research and innovation efforts have led to crucial breakthroughs in the efficient generation of hydrogen from solar energy. The efficiency and stability of solar energy conversion to hydrogen have been greatly enhanced in photoelectron chemical systems through the restructuring of their design and the resolution of issues pertaining to light absorption and reflection that were present in conventional systems. The hybrid hydrogen storage technology, which integrates solid-state hydrogen storage and high-pressure gas storage, leverages the respective benefits of these two storage methods. This approach enables rapid charging and discharging rates, as well as high volumetric hydrogen storage densities. Consequently, it enhances the reliability of hydrogen supply capacity. In contrast, hydrogen reelectrochemical technology is capable of converting the chemical energy of hydrogen into electrical energy through the utilization of fuel cells. This process exhibits a high level of efficiency and does not produce any emissions, thereby addressing the efficiency and environmental concerns associated with conventional hydrogen combustion engines. The advancement of these technologies offers increasingly viable and environmentally-friendly options for the utilization of hydrogen energy across various sectors, thereby expediting the commercialization and dissemination of hydrogen energy. Through extensive research and ongoing development, it is anticipated that hydrogen energy will assume a heightened significance in facilitating the energy transition and achieving carbon neutrality.

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