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Structure models and nano energy system design for proton exchange membrane fuel cells in electric energy vehicles

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ABSTRACT

Electric vehicles require fuel cells with a highly specific energy for the purpose of environmental protection and energy saving. However, proton exchange membrane vehicle fuel cells (PEMFC) face problems in terms of energy conversion efficiency, power density, costs and lifespan. This paper reviews key technical issues regarding the application of vehicle PEMFC especially the integration of nano-electro-catalytic energy system with high-performance electrolyte membranes. It also discusses the relation between vehicle PEMFC membrane structures and electrode performance revealing the nanostructured system model and the membrane electrode interface characterization. Manipulation of vehicle PEMFC electrode structure and quantitative characterization of the nanoscale catalyst interface are summarized aiming at improving Pt utilization efficiency, ionic conductivity and nano membrane electrode performance.

Contents

1. Introduction

The use of traditional energy resources faces a number of problems like fluctuating oil prices, turmoil in oil-producing regions and depleting oil reserves. If the world fails to find practical alternative energy resources, the future development of society will be greatly limited. There are many kinds of alternative energy sources such as hydro, wind, tidal, geothermal, biomass, solar and hydrogen (fuel cell) [1,2], and these renewable energies are able to recycle. Since electric vehicles aim to protect the environment, hydrogen with zero emissions has become an important emerging energy. Applications of hydrogen include direct combustion and fuel cells. In terms of pollution control, efficiency and applicability, the fuel cell will become an important energy option for the future

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[2,3]. The fuel cell of electric vehicles combines fuel with cells to produce a reliable energy system, which has a continuous supply of fuel generating power continuously, with no environmental pollution. Additionally, electric vehicles have greater energy efficiency and operating stability than traditional internal combustion engines. Proton exchange membrane fuel cells (PEMFC), as a focus of new energy vehicles, provide the world's industrial development with an excellent opportunity for energy transformation [3,4]. Compared with phosphoric acid, molten carbonate and solid oxide fuel cell, PEMFC features include a long lifespan, light weight, small size, high specific power, low operating temperature and a simple design [4,5]. Its working temperature is 70–100 °C [6], and the working efficiency is up to 0.45–0.55 [7,8], which is particularly suitable to serve as an electric vehicle power[9]. Therefore, the market potential is attracting the world's attention, and there is a wide application prospect. Researchers around the world are competing for PEMFC power systems and PEMFC stack, and in the next ten years, the world is expected to have one million fuel cell vehicles in operation [10].

PEMFC is a new energy system without combustion that directly turns chemical energy from fuel into electrical energy through an electrochemical reaction. PEMFC has positive and negative poles separated by electrolytes [11]. Inside a vehicle PEMFC, hydrogen in the fuel and oxygen in the oxidant react respectively at positive and negative poles to produce water while generating the current as shown in Fig. 1 [12]. When vehicle PEMFC works, hydrogen is supplied to the anode and air to the cathode. At the negative electrode, hydrogen is decomposed into H^+ and an electron. H^+ enters the electrolyte, and the electrons move towards the positive pole through the external circuit. At the cathode, oxygen in the air and hydrogen ions in the electrolyte absorb electrons arriving at the positive electrode to form water. When the supply of fuel and oxidizer is continuous, PEMFC can continuously generate electricity [13,14]. Hydrogen is the fuel for vehicle PEMFC, and oxygen obtained from the air is the oxidant for PEMFC. Hydrogen with a high electrochemical reactivity can be derived from oil, natural gas and methane [15,16]. PEMFC stack uses polymer as its electrolyte membrane allowing H^+ to pass through to reach the cathode where it is reduced [17].

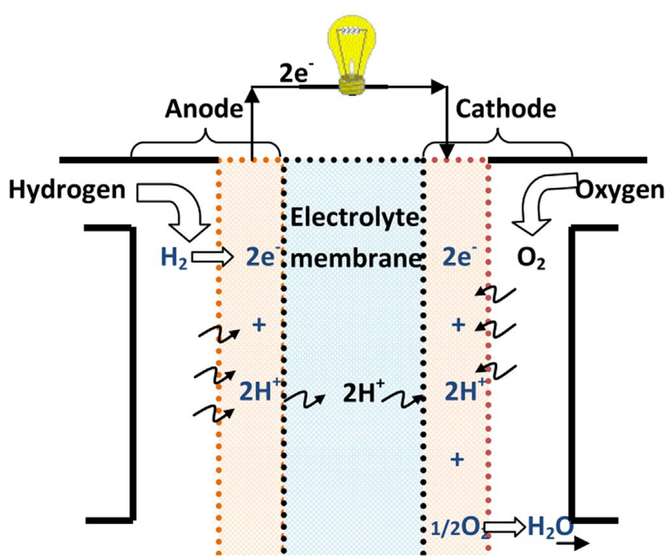

Fig. 1. PEMFC structure and diagram [12].

The core structure of vehicle PEMFC consists of a membrane, electrode, catalyst layer, gas diffusion layer and bipolar plate. The membrane is a polymer film for proton conduction composed of two surfaces, which are the catalytic layers of positive and negative electrodes. This means that between the negative and the positive electrode, there is a polymer proton exchange membrane. There is also a gas diffusion layer between the electrode, catalyst layer and the bipolar plate [18]. The proton exchange membrane is able to transfer hydrogen ion and isolate the gas. Appropriate moisture is helpful for hydrogen ion conduction, but too much water will stay in the negative electrode and affect the oxygen delivery as shown in Fig. 2 [19]. However, inadequate water management will make the film too dry increasing the impedance for hydrogen ions and deteriorating the proton conductivity.

The review shows that thermal management, water management and PEMFC stack models significantly improve the performance of PEMFCs, thus supporting longer mileage and service life, while providing new ideas for the PEMFC stack design of renewable energy vehicles. Compared with other power PEMFC, PEMFC stack are advantageous in addressing the requirements raised by PEMFC electric vehicles, such as, long mileage, high-current charging, and safety. Therefore, PEMFCs are reliable and feasible for the deployment in electric energy vehicles.

To address the demand for vehicles using PEMFC energy with high-performance electrodes, this paper discusses nano energy system and the structural design for PEMFC electrodes while giving special attention to three characteristics: thermal management, water management and PEMFC stack. The structural management model, PEMFC stack mechanism and the construction process of stack electrodes of PEMFC technology are introduced. By analyzing heat and water transmission and characterizing the stack structure, energy management system, surface and interface property at the different scales and levels, this paper reveals the intrinsic link between how an energy management system is structured and performs. It combines the management system model with the application of high-performance stack electrodes

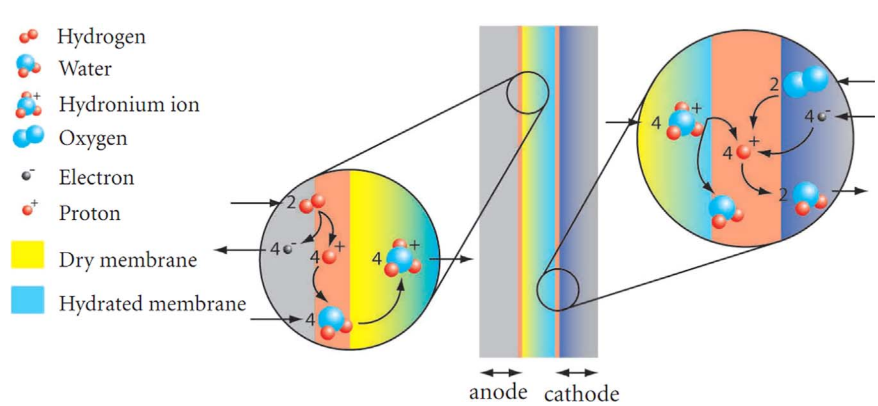

Fig. 2. Proton exchange membrane structures with nanoscale dynamic interface [19].