

A Short Review on the Development of Anode Materials for Proton Conducting Fuel Cell

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Abstract: This review focuses on a summary of the development of anode materials used in proton conducting fuel cell (PCFC). This type of fuel cell has high conversion efficiency which is about 40 to 72%, versatile technologies, durables, and low-pollution power generation system. This paper also emphasis on the properties of pure anode and metal anode composite for PCFC application. Furthermore, discussion is given more on Ni based anode composite as Ni metal has been widely used during the past decades due to its high catalytic behaviour compared to others.

Keywords: Anode composite, proton conductor, fuel cell

Nowadays, scientists and engineers are moving towards producing renewable, clean and efficient energy sources that are sustainable. Due to great potential of solid oxide fuel cells (SOFCs) to be the most efficient, low environmental pollution, and versatile technology for the chemical-to-energy conversion, this fuel cell is being actively developed by the experts world-wide [1]. There are two types of SOFCs which are conventional SOFCs (O²⁻-SOFCs) and proton conducting fuel cells (PCFCs or H⁺-SOFCs). Conventional SOFCs have high operating temperatures which are more than 700°C and up to 1000°C, which these can caused many materials problem such as cell degradation, technology, and safety issues [2].

In order to reduce the high operating temperatures, many novels of SOFCs are being introduced such as an anode-supported proton conducting fuel cells with thin film electrolytes. In the simple PCFC system, there are three major components involves which are anode, electrolyte and cathode parts. In terms of materials study, works on anode materials are quite less in number compared to electrolyte and cathode. Thus, it motivates us to write a short review on the development of anode materials for proton conducting fuel cell application.

Anode is among the most important part in the SOFCs. It is responsible to facilitate the oxidation of fuel and transport the electron from the reaction site to current site. In PCFC, materials used for anode side must have the ability to diffuse fuel, and transport the hydrogen ion (H⁺) through electrolyte layer to cathode side efficiently by having sufficient porosity which in the range of 30-40 %vol [3]. Principally, anode must be stable in terms of chemical, morphological and structure in fuel cell environment. In

addition, anode should be stable in long term operation because any notable changes can lead to cell degradation and lowered the overall performance of the cell [2, 4-5]. For electrochemical reaction to take place in reducing environment at operating temperature for PCFC (400 – 800 °C), anode must possess a high electronic conductivity in order to reduce the ohmic losses.

Pure anode of Li^+ , Cu^{2+} , Co^{2+} , Ni^{2+} , Zn^{2+} , Pt^{2+} , Fe^{3+} , Al^{3+} , Ti^{4+} , Zr^{4+} , Ge^{4+} , Sn^{4+} , Pb^{4+} , and Nb^{5+} are the examples of anode materials with high catalytic that usually being used in fuel cell. The most promising and profound metal is Nickel (Ni) which it possess the excellent catalytic components and has lower cost compared to proton exchange membrane fuel cells (PEMFCs) and phosphoric acid fuel cells (PAFCs) that used platinum (Pt) as their anode material [6]. Pure Ni anode possesses a good electrical properties, low melting point (1453K), and high electronic carrier that can enhance the overall performance of the cell. Anode must be chemically compatible with electrolyte as well as with cathode typically at higher operating temperature. Chemical interaction between anode with fuel and electrolyte must be limited in order to reduce any secondary phase formation and to increase the reduction stability. Thermal expansion of the anode must match will other components in the cell to avoid delamination or crack during fabrication process. Other specification for anode cermet is it must have adequate porosity which is between 20 to 40 vol% [7-8] to permit gas transport to the reaction sites.

The anode layer must consists of high electronic and ionic conductivities and chemically stable in reduction process [5]. Unfortunately, delamination, cracks and bending tend to happen due to mismatch of thermal expansion coefficient (TEC). The Ni anode layers prone to curl and twist when other cell components such as electrolyte and cathode layered on it due to different TEC. In addition, Ni also tends to agglomerate as it has higher TEC compared to proton conductor electrolyte. TEC of proton conductor electrolyte material such as yttrium doped barium cerate-zirconate oxide (BCZY) is $8.53 \times 10^{-6} \text{ K}^{-1}$ which is lower than TEC of Ni ($16.9 \times 10^{-6} \text{ K}^{-1}$) [4]. A large difference of TEC value between Ni and BCZY causes problems such as delamination and chemical reaction between anode and electrolyte components. Hence, to overcome the problem, metal anode composite material is actively being introduced in the PCFC research and application.

Ni is one of the metals that conventionally used in the conventional SOFCs. It has high catalytic behavior that effectively breaks the hydrogen bond (H_2) to form hydrogen ion (H^+) and eventually help to enhance the performance of the cell. However, Ni can easily agglomerate after operating in a long time due to low stability in redox process. Not only that, Ni also tends to involve in carburization and sulphidation after long operation that consequently caused delamination between anode-electrolyte layers. Hence, by mixing Ni with electrolyte materials to form composite anode can slow down the carburization and sulphidation processes at the anode side.

For high temperature applications, the development of anode composite material started with the introduction of NiO-YSZ (YSZ = yttria stabilized zirconia). However, at

intermediate temperature, the performance of the cell using this material dramatically dropped due to low ionic conductivity. Therefore, the use of proton conductor material for example BCZY has been introduced as an anode material at intermediate temperature [3]. A composite of Ni which is electronic conductor with BCZY which is proton conductor is the example of anode material that widely used in the fabricating an efficient anode layer [2]. The pores between NiO and BCZY grains help to facilitate the fuel supply. Furthermore, the electrolyte material in anode side can also reduce the agglomeration of Ni and eventually can lengthen the triple phase boundary (TPB) which also known as active site [8].

In conclusion, The development of anode materials for PCFCs is widely and intensively studied by the scientists and researchers to achieve a high efficiency power source. Both conventional SOFCs and PCFCs usually used Ni based anode composite as Ni is a promising electronic conductor that have high catalytic behavior. Nevertheless, up to-date, Ni with proton conductor material can be considered as the best and suitable metal anode composite for PCFC application

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