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Review Article

Carbon and non-carbon support materials for platinum-based catalysts in fuel cells

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ABSTRACT

Carbon and other platinum-supporting materials have been studied as electrode catalyst component of low-temperature fuel cells. Platinum (Pt) is commonly used as the catalyst due to its high electro-catalytic activity. Current research is now focusing on using either modified carbon-based or non-carbon-based materials as catalyst supports to enhance the catalytic performance of Pt. In recent years, Pt and Pt-alloy catalysts supported on modified carbon-based and non-carbon-based materials have received remarkable interests due to their significant properties that can contribute to the excellent fuel cell performance. Thus, it is timely to review this topic, focusing on various modified carbon-based supports and their advantages, limitations and future prospects. Non-carbon-based support for Pt and Pt-alloy catalysts will also be discussed. Firstly, this review summarises the progress to date in the development of these catalyst support materials; from carbon black to the widely explored catalyst support, graphene. Secondly, a comparison and discussion of each catalyst support in terms of morphology, electro-catalytic activity, structural characteristics, and its fuel cell performance are emphasized. All the catalyst support materials reviewed are considered to be promising, high-potential candidates that may find commercial value as catalyst support materials for fuel cells. Finally, a brief discussion on cost relating Pt based catalyst for mass production is included.

Contents

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Introduction

Carbon 60, or C_{60}, was discovered in 1985 [1] by applying high temperature to graphite. Carbon atoms can bond together in many different arrangements, which are called the allotropes of carbon. Carbon is distinct among all chemical elements in that it can be found in many different forms and with varying micro-textures. The diverse morphologies of carbon make it an attractive material that can be used in a wide range of electrochemical applications. The interaction between a carbon support and platinum (Pt) plays a large role in the electrocatalytic properties of Pt/C. This interaction can be improved by modifying the carbon support surface to form suitable functional groups and better chemical links at the Pt/C interface [2]. To produce an ideal and active electrocatalyst, a carbon support with suitable properties (i.e., high surface area, good crystallinity and high conductivity) should be considered because it can significantly affect the preparation of supported catalysts and the performance of the fuel cells.

According to Antolini (2009) [3], it is very challenging to develop carbon supports with high specific surface area, high electrical conductivity, suitable porosity and high stability in a fuel cell environment. Carbon supports can have a large impact on the electrochemical activities of the fuel cells. Carbon supports should possess a high proportion of mesoporous regions (20–40 nm) to provide a large surface area that is accessible to both the catalyst and the monomeric units of the Nafion ionomer to help excite the diffusion of the chemical species [3]. It has been reported that carbon materials with good crystallinity and high specific surface area can provide the maximum dispersion of Pt nanoparticles and at the same time enhance the electron transfer, which can contribute to better fuel cell performances [3]. In various forms, carbon is thermodynamically stable below 0.2 V and kinetically stable above that potential ($C + 2H_2O \rightarrow CO_2 + 4H^+ + 4e^-$, $E^\circ = 0.207$ V), which means that at higher potentials, carbon tends to be thermodynamically unstable and corrodes easily [4]. However, this limitation can be overcome *via* the oxidation process of carbon itself, which can withstand the high potential applied in fuel cell applications [5].

A catalyst is required to increase the rate of the particular catalytic reaction [6] and Pt is the catalyst material used for both anode and cathode in fuel cells, to catalyse the oxidation and reduction reactions. However, the Pt catalysts are not economically feasible due to low surface areas, therefore, support materials are required to obtain a high dispersion and a narrow distribution of catalyst that can also interact and influence the catalytic activity. The catalyst support materials greatly influence the cost, performance, and durability of polymer electrolyte membrane fuel cells (PEMFCs) and direct methanol fuel cells (DMFCs) [4,7–11]. The durability of the catalyst is also greatly dependent on its support. The requirements for catalyst support materials are (i) high specific surface area (should be greater than 100 $m^2\ g^{-1}$) [12] so that the support materials are able to provide a maximum substrate area for good dispersion of the Pt catalyst nanoparticles; (ii) low combustive reactivity under dry and damp air conditions at low temperatures (<150 °C); (iii) high electrochemical stability when tested in fuel cell conditions; (iv) high proton and electronic conductivity, as a good conductive support material acts as a path that results in better electron transport between the support itself and the catalyst; (v) easily recoverable metal (Pt) in the used catalyst; and (vi) strong interaction between catalyst and the support material, which can influence the electronic nature of the Pt catalysts, thus improving the catalytic properties and enhance the electrocatalyst stability [3,7,13,14]. However,

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