Catalysis Communications 68 (2015) 67–72

Contents lists available at ScienceDirect

Catalysis Communications

journal homepage: www.elsevier.com/locate/catcom

Short communication

3D-niobium oxide supported platinum as an effective and durable oxygen reduction catalyst

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ARTICLE INFO

Article history:
Received 25 March 2015
Received in revised form 3 May 2015
Accepted 4 May 2015
Available online 6 May 2015

Keywords:
3D-niobium oxide
Platinum catalyst
Durability
Oxygen reduction reaction

ABSTRACT

We have successfully synthesized a 3D-NbO_x supported Pt composite as oxygen reduction reaction (ORR) catalyst. 3D-NbO_x support is prepared by using KIT-6 hard template, and 3D-NbO_x supported Pt composite is prepared by reducing H_2PtCl_6 and depositing Pt nanoparticles onto 3D-NbO_x framework. Physical tests show that 3D-NbO_x has an ordered framework, and that in Pt/3D-NbO_x composite, ultra fine Pt nanoparticles are distributed along with 3D-NbO_x framework. Electrochemical tests indicate that Pt/3D-NbO_x-C composite exhibits comparable ORR activity and significantly higher durability compared with Pt/C catalyst. These findings demonstrate that 3D-NbO_x is a suitable Pt support, facilitating catalytic performance enhancement.
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1. Introduction

Polymer electrolyte membrane fuel cells (PEMFCs) are attractive power sources compared with the currently used secondary batteries due to their high energy density, zero emissions, especially no charging process [1,2]. Nonetheless, there still remain a few challenges needed to be overcome. The key issues that prohibit PEMFC development include: 1) support material corrosion; 2) support framework collapse; and 3) catalyst agglomeration. All of them are associated with the catalyst support [3,4].

The catalyst supports have long been the research interest because they help disperse noble metal catalysts, enhance catalysts utilization, and stabilize catalyst nanoparticles. The support materials can also interplay with catalytic metals and influence catalyst particle size, particle shape, thereby the catalytic activity [5,6]. Therefore, choosing an appropriate catalyst support is a vital strategy to improve PEMFC performance. Generally, the requirements for catalyst support materials can be summarized as: 1) high specific surface area, 2) high electrochemical stability under fuel cell operating conditions, 3) high conductivity, and 4) easy-to-recover Pt in the used catalyst.

In the past decades, carbon-based materials were the first choice for catalyst support because of their high surface area, high conductivity, and excellent ability to load catalysts. Vulcan XC-72 was widely used by researchers in this community [7,8]. Meanwhile, other carbon materials with novel nanostructures, such as carbon nanotubes (CNTs) [9,10], carbon nanofibers (CNFs) [11,12], mesoporous carbon (MSC) [13,14], and graphene [15,16], were also developed. Unfortunately, despite tremendous efforts on carbon materials, they cannot meet the requirements for PEMFC use, because carbon-based support materials are susceptible to corrosion under PEMFC operating conditions, especially at cathodic side (ORR) [17,18]. The harsh conditions including high temperature (80–100 °C), high potential (0.6–1.2 V), and strong acidity accelerate the corrosion processes [19]. Thus it is necessary to search for more anti-corrosive support materials for the PEMFC catalysts.

Currently, the corrosion-resistant transition metal oxides, such as TiO_2 (or Ebonex) [20–22], SnO_2 (or ITO) [23,24], IrO_2 [25,26] and WO_3 [27,28] have been intensively studied to improve the stabilities of the supports. Although certain advances have been made in this direction, there are still some problems for the developed oxide materials. In general, most of them possess low surface area, low conductivity, and some of them are unstable under applied voltage in the acidic environment. Therefore, to explore a wider range of potential support materials with desired structures and properties, suitable for catalyst supports, is the fundamental research work in fuel cell development.

In the present work, we have fabricated a three-dimensional structure of NbO_x (denoted as 3D-NbO_x) as Pt catalyst support. This type of support material has much advantages over materials of zero-dimensional (nanoparticles), one-dimensional (nanowires,

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http://dx.doi.org/10.1016/j.catcom.2015.05.003
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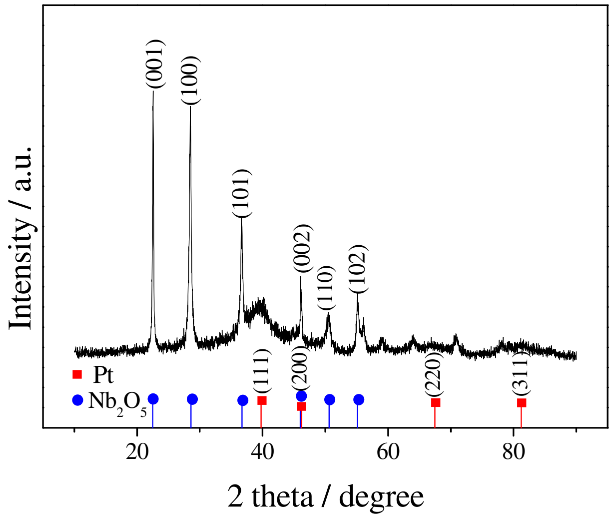

Fig. 1. X-ray diffraction pattern of Pt/3D-NbO_x catalyst.

nanotubes), and two-dimensional (nanofilms, graphene) structures. Firstly, 3D-NbO_x possesses an extremely stable framework with a three-dimensional structure, which can prevent the catalyst from collapsing during operations. Secondly, Pt catalyst can be easily supported on the 3D-framework, leading to uniform Pt dispersion along with the 3D-NbO_x framework. Thirdly, the 3D-NbO_x supported Pt catalyst (denoted as Pt/3D-NbO_x) can effectively avoid the agglomeration of Pt nanoparticles, since they keep a space with each other by anchoring Pt nanoparticles at different sites on 3D-NbO_x framework. In addition, Pt/3D-NbO_x catalyst with three-dimensional structure allows sufficient mass transfer, and facilitates high efficiency of oxygen reduction. Based on these advantages and the intrinsic chemical and electrochemical stability of NbO_x, we carried out an investigation on Pt/3D-NbO_x composite catalyst. To the best of our knowledge, this is the first report on Pt/3D-NbO_x catalyst applied for oxygen reduction reaction.

2. Experimental

2.1. Chemicals

Hexachloroplatinic acid ($H_2PtCl_6 \cdot 6H_2O$) and $NbCl_5$ were purchased from Shanghai Chemical Reagent Corp., China. Vulcan XC-72 carbon black was purchased from E-TEK and 5 wt.% Nafion solution was obtained from Dupont, USA. Except where specified, all chemicals were of analytical grade and used as received.

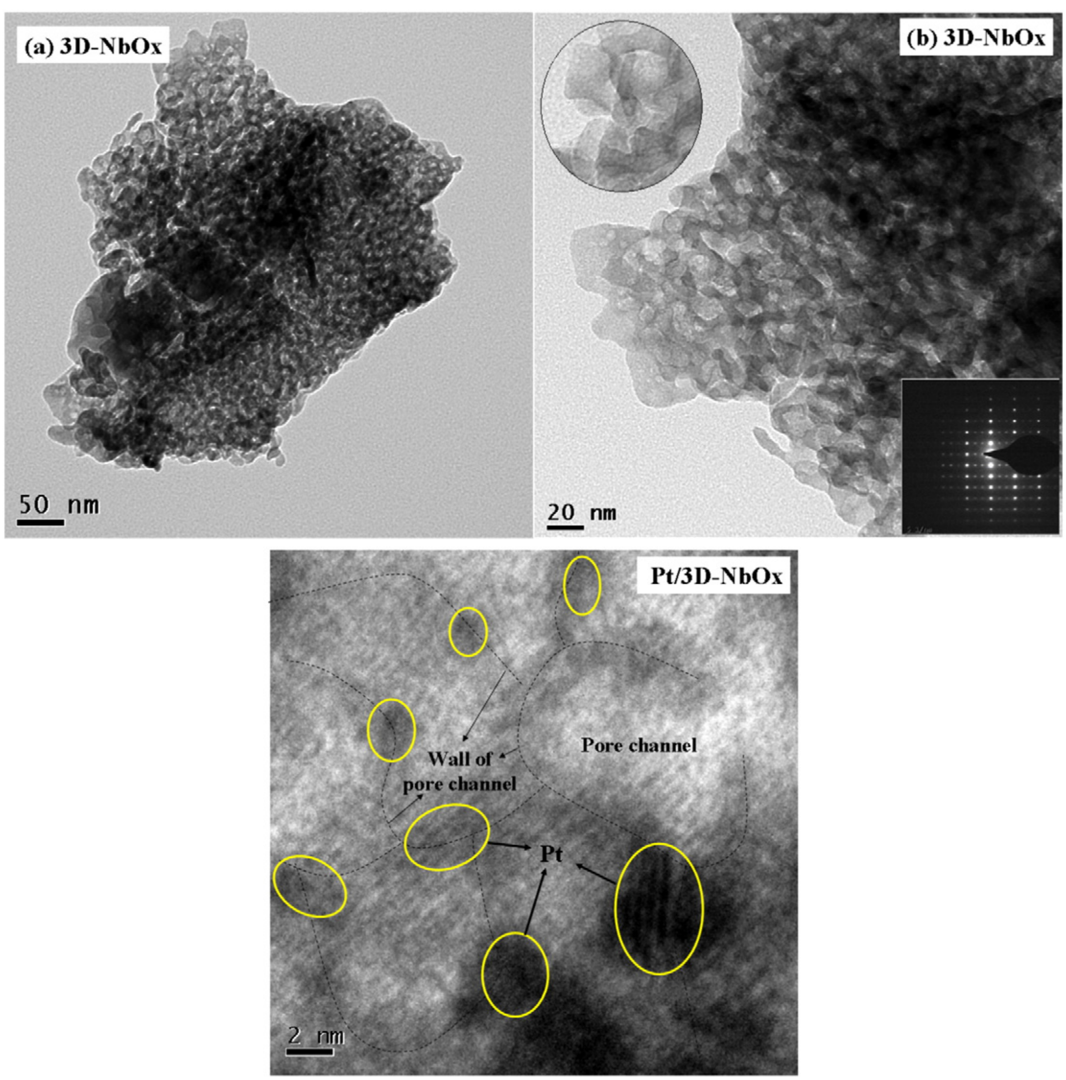

Fig. 2. Transmission electron microscopy images of the ordered 3D-NbO_x (a, b) and Pt/3D-NbO_x (c).

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