Polypyrrole nanotube-supported gold nanoparticles: An efficient electrocatalyst for oxygen reduction and catalytic reduction of 4-nitrophenol

Lihua Qiu, Yingjing Peng, Baoqiang Liu, Bencai Lin, Yu Peng, Muhammad J. Malik, Feng Yan * 
Jiangsu Key Laboratory of Advanced Functional Polymer Design and Application, Department of Polymer Science and Engineering, College of Chemistry, Chemical Engineering and Materials Science, Soochow University, Suzhou 215123, China

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A B S T R A C T

Polypyrrole nanotubes (PPyNTs)/Au nanoparticle hybrids were synthesized by using covalently attached imidazolium-type ionic liquids (ILs) as linkers. The approach involves the surface functionalization of PPyNTs with ILs, anion-exchange with Au precursor and followed by the reduction of metal ions to produce the Au nanoparticles. The surface functionalized ILs on the PPyNTs surface play an important role in the formation of Au/ILs/PPyNTs hybrids. The synthesized Au nanoparticles supported on the ILs/PPyNTs surface have a smaller particle size and better dispersion than those on pristine PPyNTs surface. The morphology and optical properties of the produced nanohybrids were characterized by scanning electron microscopy (SEM), transmission electron microscopy (TEM), Fourier transform infrared (FT-IR) spectrometer, X-ray diffraction (XRD) and UV–vis spectroscopy. The catalytic performances of Au/ILs/PPyNTs hybrids were evaluated for both the electrocatalytic oxygen reduction and catalytic reduction of 4-nitrophenol in the presence of NaBH₄. The results revealed that the Au/ILs/PPyNTs hybrids are effective electrocatalysts for dioxygen reduction and for the reduction of 4-nitrophenol.

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1. Introduction

Significant advancements in conducting polymers have prompted the development of electronic, optics, catalysis, energy storage, and biological systems [1–5]. In recent years, nanotubular conducting polymers have attracted much attention due to their interesting electrochemical properties caused by their small dimensions and high surface area [6–10]. Among the reported conducting polymer nanotubes, polypyrrole nanotubes (PPyNTs) have gained popularity because of their relatively high conductivity, redox properties, ion exchange capacity, easy preparation, excellent environmental stability and hitherto a large variety of applications [11–15]. In addition, PPyNTs can be synthesized chemically in a bulk quantity from benign aqueous environment in ambient conditions, without the use of high technology and sophisticated instruments. These features make PPyNTs highly attractive for various future applications. Typically, there is an increasing interest in the use of PPyNTs as templates for the dispersion and stabilization of semiconductors and metal nanoparticles (NPs) [16–18].

Recently, several synthetic methods have been developed to deposit the metal NPs on the surface of nanostructured polypyrrole (PPy) [19–22]. However, most of these methods involve a tedious assembly process and usually require multistep reactions [21]. Furthermore, the amount and size dispersion of metal NPs deposited on the PPy by assembly is greatly limited because there are insufficient binding sites for anchoring the precursors of metal ions or metal NPs on the PPy surface [22,23]. Therefore, it has been realized that it is necessary to introduce surface anchoring groups on the PPy surface to provide more binding sites.

Ionic liquids (ILs) are organic salts that are liquid in their pure state near ambient conditions. They have gained a great deal of both academic and industrial attention because of their low volatility, high stability, high ion conductivity and wide electrochemical activity. Among the novel properties, the excellent ion-exchange capability makes ILs very useful in the preparation of functional materials via the ion-change methods [24–29]. For example, carbon nanotubes surface-functionalized with ILs or poly(ionic liquids) (PILs) have been used as the stabilizer or linkers to deposit the metal NPs, and the resultant nanohybrids exhibit high catalytic performance [30–32].

Herein, we report an effective way of coating PPyNTs surface with controllable coverage of Au NPs. The approach involves surface functionalization of PPyNTs with imidazolium-type ILs, anion-exchange with Au precursor and followed by the reduction of metal ions. This work represents a new type of three-component Au/ILs/PPyNTs hybrid nanocatalyst with two main advantages: (1) PPyNTs can be surface functionalized in a mild conditions, which not only introduce a large number of functional groups on the...