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Digital versatile disc bipolar electrode: A fast and low-cost approach for visual sensing of analytes and electrocatalysts screening

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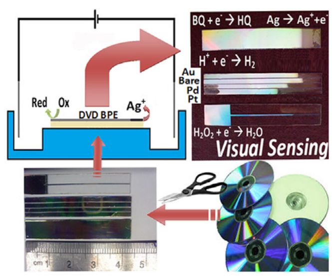
HIGHLIGHTS

- DVD-R is used to create low-cost bipolar electrodes.
- H_2O_2 and benzoquinone are detected as model targets to prove sensing applications of DVD BPEs.
- HER activity of catalysts are compared to prove screening applications of DVD BPEs.

GRAPHICAL ABSTRACT



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ABSTRACT

This work represents a new, extremely low cost and easy method for fabrication of bipolar electrode (BPE) for rapid and simultaneous screening of potential candidates for electrocatalytic reactions and sensing applications. Our method takes advantage of the silver reflective layer deposited on already available recordable digital versatile disc (DVD-R) polycarbonate substrate which acts as BPE. Oxidation of the reflective layer of the DVD-R in anodic pole of the BPE results in a permanent and visually measurable dissolute length. Therefore, one could correlate the electrocatalytic activity of the catalyst at the cathodic pole of the BPE, as well as the concentration of analyte in the solution, to the dissolution length of the BPE. To illustrate the promising applications of this new substrate as BPE, p-benzoquinone (BQ) and hydrogen peroxide were tested as model targets for the sensing application. Moreover, in order to show the feasibility of using DVD BPEs for screening applications, the electrocatalytic activity of Pt, Pd, Au, and pristine DVD substrate toward hydrogen evolution reaction (HER) were compared using an array of BPEs prepared on DVD substrate.

1. Introduction

When a sufficiently high electric filed is applied across an electrolyte solution containing an electrically conductive object and electroactive species, faradaic reactions are induced at the two ends of the conductive object parallel to the electric field in the electrolyte. As the electro-neutrality should be maintained within the conductor, reactions occur separately and simultaneously with the same rate at the two ends of the object [1]. Therefore, this object which acts as both cathode and anode is called a bipolar electrode. A bipolar electrode does not require direct electrical connection to the power supply; as a result, in principle, an array of arbitrary number of electrodes can be employed using a single voltage source [2]. Besides, each bipolar electrode in the array can be separately modified for any specific application [3,4].

Recently, bipolar electrochemistry has been adopted in some

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fields in chemistry such as analysis [4–23] and screening of electrocatalysts [3,24–27]. Electrocatalyst screening and analyte detection are signaled through fluorescence, electro generated chemiluminescence (ECL), and anodic dissolution of a metal film [28]. Anodic dissolution, which is dissolution of a metal film deposited on anodic pole of BPE due to the occurrence of cathode reaction on the cathodic pole of the electrode, is advantageous over ECL and fluorescence methods in that it does not require optical readout equipment and can be detected by the naked eye. Moreover, dissolution process does not require solution phase reagents, and finally, the sensitivity and detection limit is controlled by thickness and cross sectional area of deposited metal film [21,28].

Most relevant to the present study are the four recent investigations by Crooks et al. Crooks and coworkers first reported a sensing platform based on dissolution of Ag film deposited on gold coated slides. DNA hybridization is then signaled using prepared bipolar electrodes [21]. This method is then further developed and employed for screening the electrocatalyst for oxygen reduction reaction (ORR) using bipolar electrochemistry [3]. BPEs were fabricated by deposition of parallel Ag microbands on Indium Tin Oxide substrate and the extent of Ag electro-dissolution was related to the ORR activity of catalysts. In another work, bipolar electrochemistry was employed for parallel screening of bimetallic electrocatalyst candidates for the ORR. The operating principle was similar to the previous work except for the Ag microbands which were replaced by Cr [26]. Recently, they demonstrated the utility of the same technique for screening of electrocatalyst candidates for the HER by investigating bi- and tri-metallic systems involving Co, Fe, Ni, Mo, and W [27]. However, in most of these reports the method used for fabrication of BPEs for screening and sensing applications is sophisticated and requires multiple steps of photolithography and physical vapor deposition technique which are not available in a standard chemistry laboratory.

Gold compact discs (CD) have been used for preparing inexpensive disposable gold working electrodes in electroanalytical chemistry [29,30]. This cheap substrate has also attracted attention for designing microfluidic and lab on chip devices [31–33]. Recently, the capability of using Ag electrodes manufactured from silver CD and DVD for the determination of hydrogen peroxide in traditional electrochemical setup have been investigated [34–36]. DVD-Rs are composed of two polycarbonate plates. One of them is coated with an organic dye followed by sputtering a thin layer of reflective metal film.

Herein, we introduce a method for fabrication of BPEs using conductive surface of the DVD-R reflective layer for sensing applications and for rapid screening of electrocatalysts in bipolar electrochemistry. The setup used is shown in Fig. 1. The BPE we propose here has the advantage of electrodissolution of the reflective layer at the anodic pole of the BPE that provides direct visual means for obtaining information about either the concentration of analyte in the solution or the electrocatalytic activity of the catalyst deposited on the cathodic pole of the BPE. The most effective electrocatalyst or the highest concentration of analyte results in oxidation of a longer length of the DVD-R electrode. Using array of BPEs makes the experiment even faster and more efficient; accordingly, it was proved that making arrays of BPEs on the DVD-R is feasible. Using this simple method with extremely low-cost and widely available DVD-R electrodes, as a proof of concept, we show that the electrocatalytic activity of HER catalysts is related to the length of dissolution; therefore, activity of these catalysts can be compared based on the dissolved length of corresponding electrode. Besides, it was proved that the length of dissolution is directly related to the onset potential for HER of catalyst. For sensing applications, it was demonstrated that the dissolution length is a function of the concentration of p-benzoquinone and hydrogen peroxide which were chosen as model targets. Finally, we believe that this new substrate holds promising applications for the future investigations especially if bipolar electrochemistry devices are designed directly on DVD polycarbonate substrates and used for lab on chip applications.

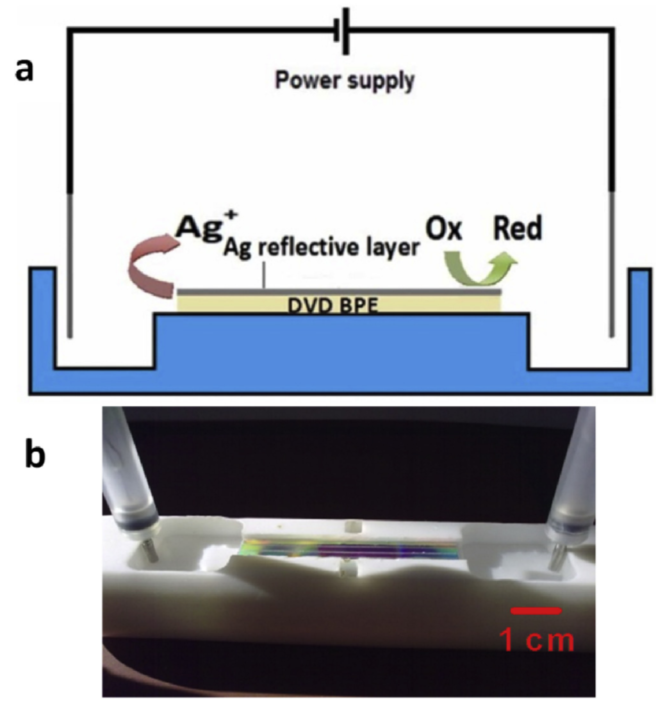

Fig. 1. (a) Schematic view of the bipolar electrochemical setup with the DVD BPE. (b) Bipolar electrochemistry device together with the DVD BPE inserted at the center of the Teflon cell.

2. Experimental

2.1. Chemicals and reagents

BQ, H_2O_2, KNO_3, K_2PtCl_6, H_2SO_4, $PdCl_2$, and $HClO_4$ were purchased from Merck. $HAuCl_4$ was purchased from Alfa Aesar. All the chemicals were used without further purification. The standard fresh stock solutions of BQ and H_2O_2 were prepared daily in 0.1 M KNO_3. All of the solutions were prepared using doubly distilled water.

2.2. Instruments

X-ray diffraction analysis (XRD) was performed with a Bruker D8/Advance X-ray diffractometer with Cu-Kα radiation at 40 kV and 40 mA. All voltammetric experiments were carried out using an Autolab PGSTAT 101 (EcoChemie, The Netherlands, driven by NOVA 1.5 software) with the conventional three electrode system consisting of a DVD working electrode, platinum wire as auxiliary electrode, and Ag/AgCl (3 M KCl) as reference electrode.

Atomic force microscopy (AFM) was performed with DME with DS 95 SPM head. A direct current (DC) power supply (MASTECH, HY3005F-3) was used for performing bipolar electrochemistry experiments.

2.3. Bipolar electrode fabrication

Bipolar electrodes used in this study were prepared by first exposing the DVD-R metallic reflective layer. For this purpose, the