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Ethanol based fuel cell on paper support

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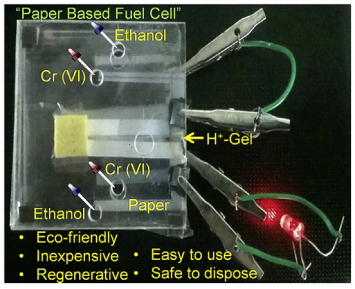
HIGHLIGHTS

- Paper based fuel cell with ethanol as fuel and dichromate as oxidant is fabricated.
- Poly (4-styrene sulfonate) based gel electrolyte is used.
- Hydrothermally synthesized molybdenum oxide nanorods are used as the catalyst.
- Maximum power densities of 6.32 mW cm-2 is obtained with catalyst.
- An LED is illuminated using a prototype stack of two cells.

GRAPHICAL ABSTRACT



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ABSTRACT

Easily disposable low cost fuel cells as power sources are environmentally benign alternates to batteries for powering micro-analytical systems. In this regard, for the first time, an ethanol-dichromate fuel-oxidant microfluidic fuel cell is implemented on a paper scaffold. In this cell, a proton conducting poly (4-styrenesulfonate) based gel electrolyte enables proton transport from the anode to the cathode. Hydrothermally synthesized molybdenum oxide nanorods catalyze dichromate reduction and ethanol oxidation at the respective electrodes. A peak power density of 6.32 $mWcm^{-2}$ is achieved with the catalyst. However, the cell without catalyst delivers a maximum power density of only 2.74 $mWcm^{-2}$. The compositions of the catholyte and anolyte streams and molybdenum oxide loadings are optimized. A stack of two cells connected in series illuminates a 3 mm red light emitting diode for over 40 min. This real time demonstration showcases the potential of this cell as an alternative to batteries for powering micro-analytical devices.

1. Introduction

In recent times, energy conversion devices which rely on the self transporting property of paper for metering reactants have received significant interest from researchers worldwide as these devices can be easily integrated into micro total analysis systems (-TAS) and lateral flow diagnostic devices such as glucometers, dengue test kits, pregnancy detection kits, paper based centrifuge for blood processing and paper machine for molecular diagnostics [1–3]. Moreover, paper is ubiquitious, bio-degradable and can be cut into any shape. These devices can be made from low cost, easily available and easily disposable components, and do not require pumps or moving parts. A variety of cell architectures with the sole objective of miniaturization of paper-based microfluidic devices have been proposed [4,5]. Use of these

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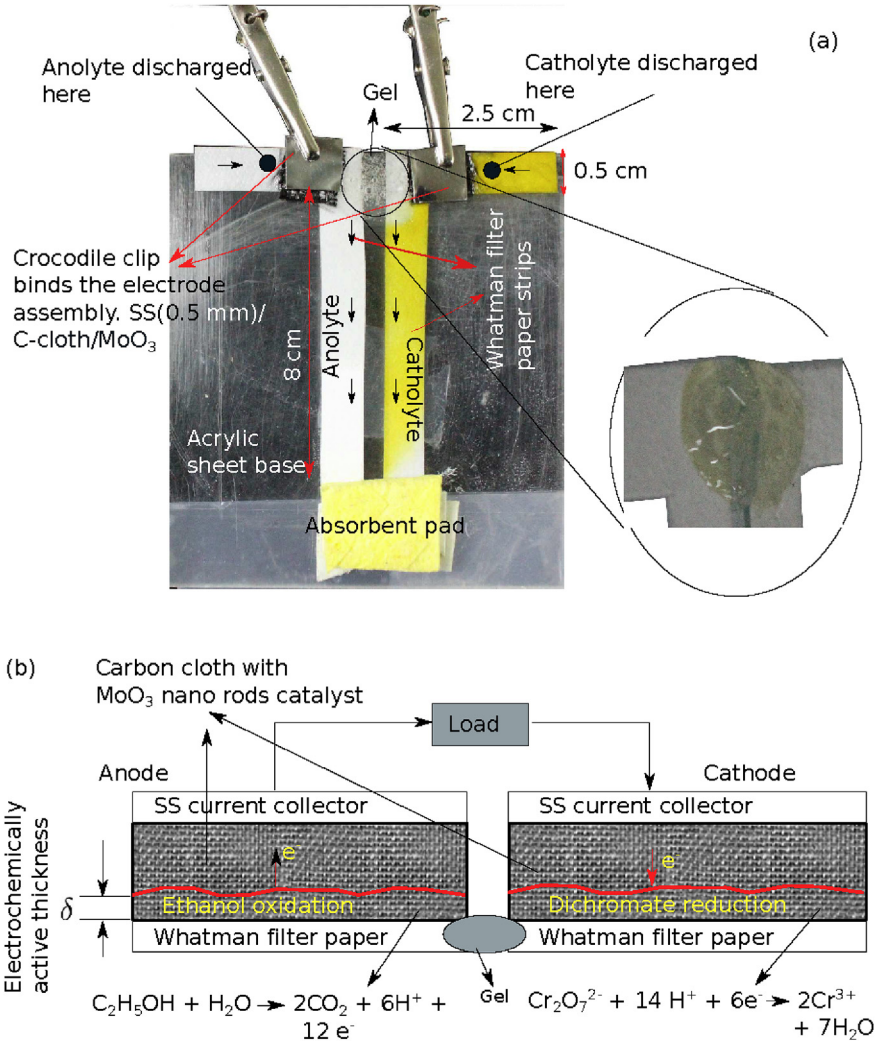

Fig. 1. (a) Photograph of the cell assembly and (b) Schematic of the cross sectional views of the anode and cathode.

devices in point of care diagnostic devices can revolutionize rural health care. Paper based fuel cells, which rely on the parallel laminar flow of anolyte and catholyte utilizing different fuels such as methanol, hydrogen peroxide and formic acid have been demonstrated recently [6,7]. In the case of parallel flow membraneless fuel cells, an electrolyte phase is required for the transport of ions from one electrode to the other. Therefore, the fuel and oxidant needs to be mixed with electrolytes to form the anolyte and catholyte. Although the cell performances reported in such systems are fairly good, the fuel/oxidant cross-over continues to limit the cell performance in membraneless configurations. Paper-based fuel cells with poly (acryl amide) based proton conducting gel as a separating membrane to limit the anolyte/catholyte cross over, with relatively stable and regenerative cell performances, have also been reported [8]. These systems can maintain the open circuit voltage (OCV) of the cell without appreciable drop over time as compared to the membraneless configurations.

The fuel-oxidant redox couple plays a key role in deciding the electrochemical performance of a fuel cell. Ideally, the redox couple chosen should deliver a high standard potential and the cell reactions should not lead to the formation of hazardous by-products. Besides these aspects, the electrolyte used for forming the anolyte and catholyte should have appreciable ionic conductivity to facilitate easy transport of ions within the system. While many fuel-oxidant pairs using different acidic and alkaline electrolytes have been reported in the literature, the ethanol-dichromate fuel-oxidant combination has not been reported so far to the best of our knowledge. Ethanol is low cost, environment friendly, easily available, easy to store and handle, and has a high energy density (8.0 kW h kg^{-1}) [9,10]. On the other hand, potassium dichromate ($K_2Cr^2O_7$) is cheap, non-toxic and a strong oxidizing agent. Due to the slow electrochemical oxidation kinetics of ethanol, various metal-based catalysts and binary metal catalysts (e.g. Pt-Ru, Pt-Sn), trimetallic catalyst (e.g. Pt-Ru-Ni, Pt-Sn-Ni) and carbon supported metal catalysts (e.g. Pt/C, Pd/MWCNTs, PdAg/MWCNTs (multiwalled carbon nanotubes)) have been used as anode catalysts to enhance the kinetics.

These electrocatalysts have shown promising performances in direct ethanol based fuel cells (DEFC) and microfluidic fuel cells [9,11,12]. However, due to high cost and limited availability, these noble metal based catalysts cannot be used for developing low cost paper based fuel cells. Molybdenum oxide (MoO_3) is an inexpensive alternative to the above mentioned catalysts. MoO_3 has a good ethanol sensing property [13], and by preparing the same in nanostructured form, the catalytic surface area can be enhanced, which can lead to high oxidation currents. While a composite of MoO_3 with poly (pyrrole) has been used as a support for Pt-Pd nanoparticles for ethanol electro-oxidation in DEFC [14], MoO_3 as a stand-alone catalyst in paper based ethanol fuel cell has not been reported so far.

In the present study, solution phase ethanol-dichromate fuel cell is developed using filter paper as support at the room temperature. A proton conducting poly (4- styrenesulfonate) (PSS) based gel is used to maximize the cell performance. Hydrothermally synthesized MoO_3