Carbon 128 (2018) 31–37

Contents lists available at ScienceDirect

Carbon

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

A novel approach for forming carbon nanorods on the surface of carbon felt electrode by catalytic etching for high-performance vanadium redox flow battery

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ARTICLE INFO

Article history:
Received 13 July 2017
Received in revised form
21 November 2017
Accepted 22 November 2017
Available online 23 November 2017

Keywords:
Carbon nanorods
Etching
Carbon felt
Cobalt oxide
Vanadium redox flow battery

ABSTRACT

In this work a novel method is unfolded to modify carbon felts (CF) to substantially improve the performance of the electrodes for vanadium redox flow batteries (VRFBs). The carbon felt, a well-known electrode material for VRFB, is catalytically etched by cobalt oxide to form carbon nanorods on the surface of the fibers comprising the CF. Unlike conventional multistep processes to grow nano-structures on carbon felts, this method simply involves a thermal treatment of catalyst-loaded felt in air to produce well aligned nanorods on its fibers. The surface morphology is optimized by etching temperature, treatment time and catalyst type. The catalytically etched CF shows an improved surface wettability and an enlarged specific surface area about two times compared to pristine CF that lead to an improvement of kinetics towards vanadium redox reactions. When used as electrode in all-vanadium redox flow battery, the nanorod-structured CF shows around 35% higher charge/discharge rate capability at 150 mA cm^{-2} and 80% retained-capacity compared to 48% in case of un-etched CF as confirmed by a long run test with a hundred cycles of charge/discharge operation at 50 mA cm^{-2}.

1. Introduction

The environmental impacts of fossil fuels and depletion of their reserves are main reasons for the growing use of renewable energy sources and environmentally sustainable storage technologies in recent years [1]. Solar, wind, biomass and tidal are among climate-friendly energy sources. But their integration into large scale grid application is limited by their intermittent nature [2–4]. The energy storage systems (ESS) solve this issue by storing energy on large scales [5,6]. The redox flow batteries (RFBs) due to unique advantages of design flexibility, long cycle life and decoupled scaling of power and energy, are considered as one of the most suitable candidates of ESS [6–8]. All vanadium redox flow battery (VRFB) has advantage over other RFBs as it employs four different oxidation states of vanadium, V^{4+}/V^{5+} to cathode side and V^{2+}/V^{3+} to anode side, and thus minimizes crossover effect through membrane. A typical VRFB contains two electrolyte reservoirs connected to a cell that has an ion exchange membrane sandwiched between two electrodes. Both anolyte and catholyte are stored separately in external storage tanks and are circulated through the cell by pumps. V^{4+} is oxidized to V^{5+} on the cathode while V^{3+} is reduced to V^{2+} on the anode during charging and these charged species are reversed back during discharging [9–11]. The process can be described as following:

$$\text{Cathode: } VO^{2+} + H_2O \leftrightarrow VO_2^+ + 2H^+ + e^- \; E^0 = 1.00\ \text{V} \quad (1)$$

$$\text{Anode: } V^{3+} + e^- \leftrightarrow V^{2+} \; E^0 = -0.25\ \text{V} \quad (2)$$

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https://doi.org/10.1016/j.carbon.2017.11.066
0008-6223/