Journal of Power Sources 222 (2013) 498–502

Contents lists available at SciVerse ScienceDirect

Journal of Power Sources

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

Short communication

Carbon nanoporous layer for reaction location management and performance enhancement in all-vanadium redox flow batteries

M.P. Manahan [a], Q.H. Liu [b], M.L. Gross [c], M.M. Mench [b,d,*]

[a] Department of Mechanical and Nuclear Engineering, The Pennsylvania State University, University Park, PA 16802, USA
[b] Electrochemical Energy Storage and Conversion Laboratory, Department of Mechanical, Aerospace, and Biomedical Engineering, The University of Tennessee, Knoxville, TN 37996, USA
[c] Department of Materials Science and Engineering, The Pennsylvania State University, University Park, PA 16802, USA
[d] Energy and Transportation Science Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA

HIGHLIGHTS

- A thin layer of CNTs was added to all-vanadium redox flow battery electrodes.
- This is the first time a separate layer of carbon nanotubes has been used in VRFBs.
- The CNT layer was used to locate where reactions are most favorable within the cell.
- Performance increased with the CNT layer near the negative electrode flow field.

ARTICLE INFO

Article history:
Received 31 July 2012
Received in revised form
30 August 2012
Accepted 31 August 2012
Available online 10 September 2012

Keywords:
All-vanadium redox flow batteries
Polarization
Carbon paper
Reaction location
Carbon nanotube

ABSTRACT

In this study, the performance and reaction location in a VRFB was investigated with a carbon paper electrode that was modified to include a thin layer of multi-walled carbon nanotubes. The nanotube layer was introduced into the electrode at locations on the negative and positive electrode nearest the membrane and nearest the flow field. Results with the nanotube layer on the positive electrode yielded small changes in the performance, despite the location. However, when the nanotube layer was introduced on the negative electrode, the performance was greatly improved when it was closest to the current collector. In this configuration, an 8% increase in power density and a 65 mV increase in cell voltage were observed, compared to a cell with raw carbon paper. This is attributed to the increase in active area of the nanoporous structure in a location where the reaction is favored to occur.

Published by Elsevier B.V.

1. Introduction

The all-vanadium redox flow battery (VRFB) has been under significant development for grid leveling and renewable energy conversion and storage applications [1]. VRFB systems contain a negative and a positive half-cell where four oxidation states of V^{2+}/V^{3+} and V^{4+}/V^{5+} (present as VO^{2+}/VO_2^+) serve as redox couples at the respective electrodes, as shown in Eqs. (1) and (2):

$$V^{3+} + e^- \underset{\text{discharge}}{\overset{\text{charge}}{\rightleftharpoons}} V^{2+}, \quad E^0 = -0.26 \text{ V vs. NHE} \tag{1}$$

$$VO^{2+} + H_2O \underset{\text{discharge}}{\overset{\text{charge}}{\rightleftharpoons}} VO_2^+ + 2H^+ + e^-, \; E^0 = 1.00 \text{ V vs. NHE} \tag{2}$$

Carbon-based porous materials have been widely used as electrodes on both the negative and positive half-cells. Carbon felt materials have been typically employed [2,3], however recent studies have shown that carbon paper (CP) can yield significantly enhanced performance [4,5], although possible degradation issues are not yet not fully understood or resolved. In particular, Refs. [4,5] show a maximum power density of more than five times other published levels at 60–100% state of charge range.

* Corresponding author. Electrochemical Energy Storage and Conversion Laboratory, Department of Mechanical, Aerospace, and Biomedical Engineering, The University of Tennessee, Knoxville, TN 37996, USA. Tel.: +1 865 974 6751; fax: +1 865 974 5274.
E-mail addresses: matthewmench@gmail.com, mmench@utk.edu (M.M. Mench).

0378-7753/$ – see front matter Published by Elsevier B.V.
http://dx.doi.org/10.1016/j.jpowsour.2012.08.097

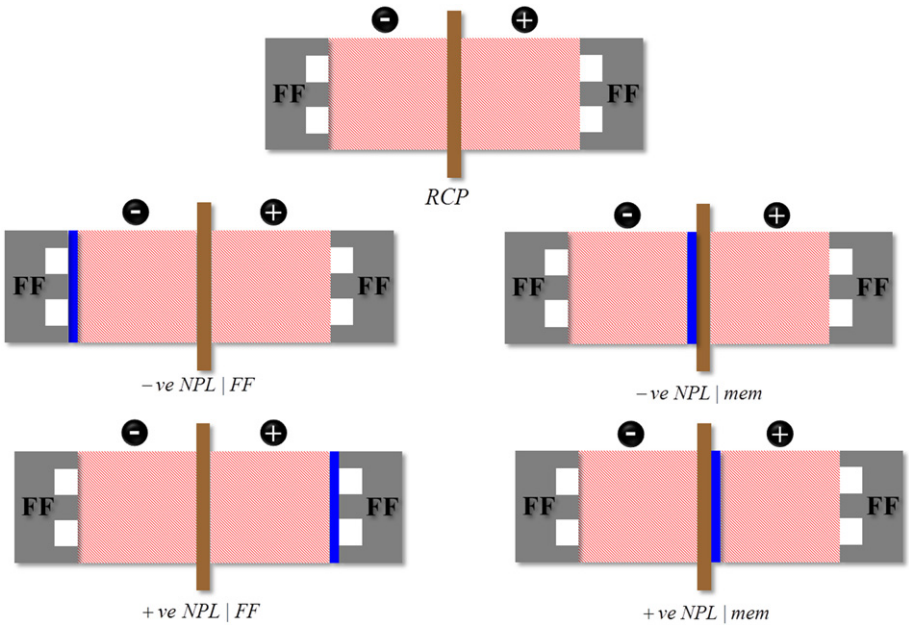

Fig. 1. A schematic of the nanoporous layer (NPL) orientations tested. The solid blue region represents the NPL, the hashed region represents carbon paper, the brown separator represents the membrane (mem), and the flow field (FF) is as labeled (not to scale). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

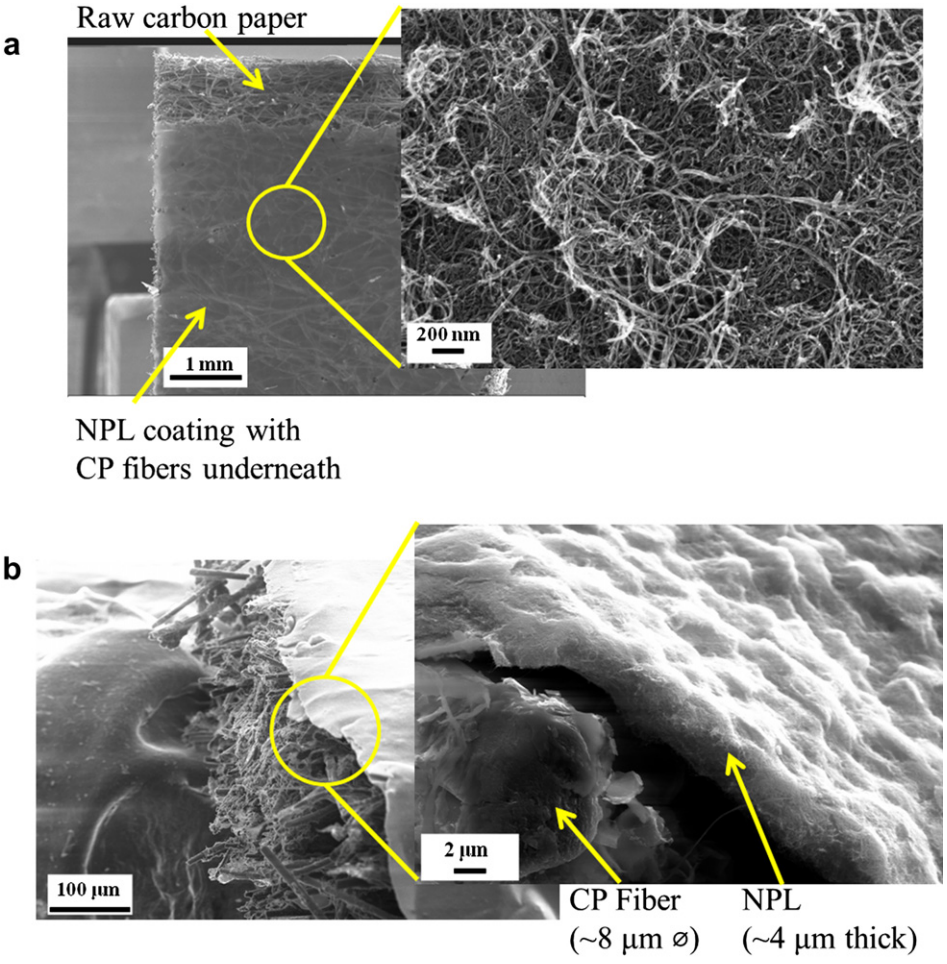

Fig. 2. (a) Top-down SEM image of CP with NPL coating and a close-up of the NPL. (b) Angled view of CP with NPL and close-up of a CP fiber and NPL.