École polytechnique fédérale de Lausanne (EPFL) Valais/Wallis
Institute of Chemical Sciences and Engineering (ISIC)
Basic Science Faculty (SB)
Energypolis, Rue de l'Industrie 17, CH-1950 Sion, Switzerland

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High Performance Direct Borohydride Fuel Cells (DBFCs) incorporating pH-gradient-enabled Microscale Bipolar Interfaces (PMBIs)

Zhongyang Wang, Shrihari Sankarasubramanian, and Vijay K. Ramani
Department of Energy, Environmental and Chemical Engineering
Washington University in St Louis

Direct borohydride fuel cells (DBFCs) can operate at double the voltage of proton exchange membrane fuel cells (PEMFCs) by employing an alkaline $NaBH_4$ fuel feed and an acidic H_2O_2 oxidant feed. The key to the realization of this system is the pH-gradient-enabled microscale bipolar interface (PMBI), which facilitates significantly different local pH environments at the anode and cathode of the DBFC. First, we provide experimental evidence using a novel recessed planar electrode (RPE) setup that the PMBI was able to maintain a sharp local pH gradient (1.05 pH units/nm) at the electrocatalytic reaction sites. When incorporated in a DBFC, the PMBI configuration enabled significantly enhanced performance as compared to either an all-anion-exchange configuration or all-cation-exchange configuration. The delivery of high-power densities (> 0.5W/cm^2) at voltages above 1 V (not accessible for most fuel cells) was attributed to the effective separation of anolyte and catholyte locally at the electrocatalytically active sites by the PMBI. Secondly, given the need to dissociate water at the interface to ensure ionic conduction, PMBIs can be efficient only when anion exchange ionomer (AEI) moieties enable fast water transport for autoprotolysis. We examined a series of polynorbornene based AEIs with a range of water uptake values to unravel the optimum water uptake required to enable high performance DBFCs. Finally, we enhanced the performance of the DBFC to a peak power density of ca. 0.9 W cm^{-2} at 1.1V by reactant-transport engineering to mitigate parasitic reactions such as borohydride hydrolysis and hydrogen oxidation. The judicious selection of the anode architecture was found to be critically important in achieving high DBFC performance. The borohydride oxidation reaction rate increased with increasing anode Reynolds number (Re) up to a critical value of Re =1000, with subsequent increases in Re offering diminishing improvements. Based on our analysis we recommend that high power DBFCs be designed to maintain Re of the flow within their anodic channels between 300-1000 and ensure a Damköhler number (Da) between $2{\cdot}10^{-2}$ and $5{\cdot}10^{-2}$. Thus, high-voltage and high-power DBFCs can be achieved through a judicious combination of materials engineering and reactor design.

CV: Vijay K. Ramani

Vijay has a Ph.D. from the University of Connecticut, Storrs, and a B.E. from Annamalai University, India, both in Chemical Engineering. Vijay K. Ramani holds the Roma B. and Raymond H. Wittcoff Distinguished University Professorship at Washington University in St. Louis (WUSTL). He is a Professor in the Department of Energy, Environmental and Chemical Engineering at WUSTL. His research interests lie at the confluence of electrochemical engineering, materials science, and renewable energy technologies. He is the recipient of the 3M Non-tenured Faculty Award (2010) and the Supramaniam Srinivasan Young Investigator Award from the ETD Division of ECS (2012). He is a past Chair of the IE&EE Division of ECS and of Area 1E of AIChE. He has served as co-editor of ECS Interface.