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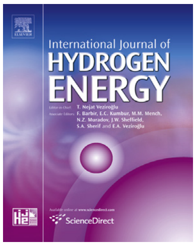

# Additive manufacturing of liquid/gas diffusion layers for low-cost and high-efficiency hydrogen production☆

*Jingke Mo* [a], *Ryan R. Dehoff* [b], *William H. Peter* [b], *Todd J. Toops* [b], *Johney B. Green Jr.* [b], *Feng-Yuan Zhang* [a],*

[a] *Nanodynamics and High-Efficiency Lab for Propulsion and Power, Department of Mechanical, Aerospace & Biomedical Engineering, UT Space Institute, University of Tennessee, Knoxville, Tullahoma, TN 37388, USA*
[b] *Oak Ridge National Laboratory, 1 Bethel Valley Rd., Oak Ridge, TN 37831, USA*

## ARTICLE INFO

*Article history:*
Received 9 November 2015
Accepted 6 December 2015
Available online 14 January 2016

*Keywords:*
3D printing
Electron beam melting additive manufacturing
Proton exchange membrane electrolyzer cell
Liquid/gas diffusion layers
Multifunctional materials

## ABSTRACT

A low-cost additive manufacturing technology, electron beam melting (EBM), is employed for the first time to fabricate titanium liquid/gas diffusion media with high-corrosion resistances and well-controlled multifunctional parameters, including two-phase transport and high electric/thermal conductivities. Its application in proton exchange membrane electrolyzer cells (PEMECs) has been investigated *in-situ* with modular galvano (MG) and galvano electrochemical impedance spectroscopy (GEIS) and characterized *ex-situ* with SEM and XRD. Compared with conventional woven and sintered liquid/gas diffusion layers (LGDLs), much better performance is obtained with EBM-fabricated LGDLs due to a significant reduction of ohmic losses. The EBM technology components exhibited several distinct advantages in fabricating LGDLs: well-controllable pore morphology and structure, rapid prototyping, fast manufacturing, highly customizable design, and economic. In addition, by taking advantage of additive manufacturing, it is possible to fabricate complicated three-dimensional designs of virtually any shape from a digital model into one single solid object faster, cheaper, and easier, especially for titanium components. More importantly, this development will provide LGDLs with well-controllable pore morphologies, which will be valuable to develop sophisticated models of PEMECs with optimal and repeatable performance. Furthermore, it could lead to a manufacturing solution that greatly simplifies the PEMEC/fuel cell components.

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☆ This manuscript has been authored in part by UT-Battelle, LLC, under Contract No. DE-AC05-00OR22725 with the U.S. Department of Energy. The United States Government retains and the publisher, by accepting the article for publication, acknowledges that the United States Government retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce the published form of this manuscript, or allow others to do so, for United States Government purposes.

* *Corresponding author*. Tel.: +1 931 393 7428.
E-mail address: fzhang@utk.edu (F.-Y. Zhang).

http://dx.doi.org/10.1016/j.ijhydene.2015.12.111

## Introduction

With a high energy density and no harmful emissions, hydrogen has the potential to play an important role as an energy carrier in the future [1–7]. However, hydrogen is not an energy source; it doesn't exist in nature in its elemental or molecular form; therefore, hydrogen must be produced. Proton exchange membrane (PEM) water electrolysis, which was first developed in the mid-1970s by General Electric based on the first solid polymer electrolyte system deployed the Gemini Space Program [8], has been among the most efficient and practical means of producing hydrogen to date. In recent years this technology has been developed significantly and has become more attractive to produce hydrogen from water and to store energy by taking advantage of renewable energy sources and new material innovations. Proton exchange membrane electrolyzer cells (PEMECs) have a number of advantages compared to other electrolysis processes, including production of hydrogen at a higher purity, capable of operation at higher current density on the electrodes leading to faster reaction, and the ability to operate at pressures up to 200 bar thus providing the advantage of delivering the hydrogen at a high pressure for the end user. These benefits all contribute to the choice of PEM based electrolysis as the best method to supply hydrogen [9–12].

A PEMEC consists of a catalyst-coated membrane sandwiched between anode and cathode electrodes. Each electrode includes a catalyst layer (CL), a liquid/gas diffusion layer (LGDL), and a bipolar plate (BP), which also acts as the current distributor (CD) and the flow field. When a sufficient electrical current is applied, water decomposes to oxygen, protons, and electrons at the anode reaction site. Protons pass through the membrane, typically Nafion, to the cathode and react with electrons to form hydrogen. By combining single cells, a PEMEC stack can supply huge amounts of hydrogen and oxygen that can be stored for later use.

One of key challenges for current PEMECs is to improve the performance and cost efficiency with the most suitable LGDLs, which are located between the catalyst layers (CLs) and the bipolar plate (BP)/current distributor (CD) in a PEMEC, as shown in Fig. 1. The LGDLs are expected to transport reactants, electrons, heat, and products, with minimum voltage, current, thermal, interfacial, and fluidic losses [13–20]. The LGDL has to meet the following challenges: (1) Reactant permeability: provide reactant water access effectively from flow channels to catalyst layers; (2) Product permeability: provide flow pathways for $H_2$/$O_2$ from catalyst-layer area to flow channels; (3) Electronic conductivity: provide electrons to all reaction sites; (4) Thermal conductivity: provide efficient heat transport and uniform heat distribution; and (5) Interfacial and mechanical properties: provide high corrosion resistance and good contacts (i.e., good interfacial electrical and thermal conductivity) with the adjacent materials/parts (BP/CD and CL), and maintain small pressure drops in the flow channel. Thus, effective LGDLs will promote a uniform current/thermal distribution at the adjacent reaction sites.

Carbon materials (carbon paper or carbon cloth), which are typically used in PEM fuel cells (PEMFCs), are unsuitable for PEMECs due to the high potential of the oxygen electrode [21]. Metallic LGDLS and bipolar plates have attracted more interest in both PEMECs and PEMFCs due to their high conductivity, rapid production, and low cost [22–24]. By taking advantage of novel designs and advanced fabrication methods, a thin-film metallic LGDL with well-controlled pore morphologies and surface properties demonstrated good functionality and water management in PEMFCs [22,25–27]. However, since material corrosion and consumption will result in poor interfacial contacts, degrading the PEMEC performance and efficiency, metallic LGDLs with higher corrosion resistance are strongly desired.

Titanium has received considerable attention as a promising structural/functional material in aerospace, marine, nuclear, electronics, medical implants, and instruments due to its high corrosion resistance even at high positive overpotentials as well as in highly acidic and humid conditions; however, difficulty in the machining of titanium and its cost have been limiting factors for its widespread application. With the development of additive manufacturing (AM) technology, which has the advantages of high precision, complex geometry capability, good repeatability, tooling-free, low-cost, and rapid batch production, several fabrication solutions for multifunctional and well-tunable LGDLs have become possible [28–30]. The electron beam melting (EBM) technology, which was commercialized by Arcam AB Corporation about 15 years ago, has greatly enhanced the AM capabilities by taking advantage of precisely-controlled and high-energy electron heating sources.

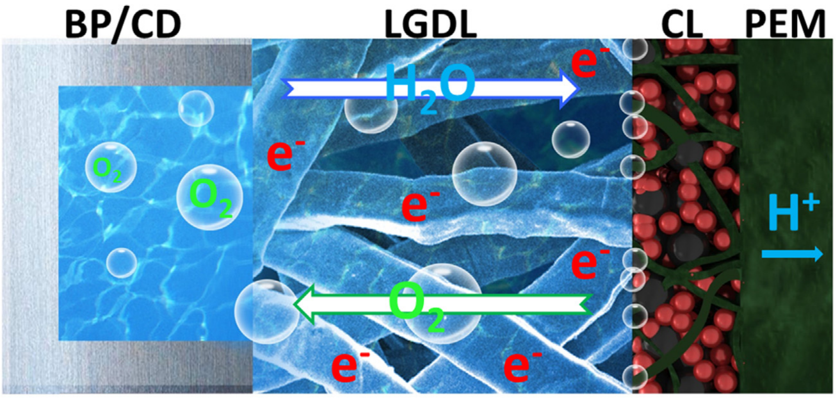

Fig. 1 – Schematic of LGDL functions at anode side.