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Gas diffusion layer using a new type of graphitized nano-carbon PUREBLACK® for proton exchange membrane fuel cells

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Abstract

A gas diffusion layer (GDL) for proton exchange membrane fuel cell has been developed using a new form of partially ordered graphitized nano-carbon black (PUREBLACK® Carbon). This material represents a new class of nano-carbons jointly developed by Superior Graphite Co. and Columbian Chemicals Co. The GDL was characterized by physico-chemical as well as electrochemical methods. The unique process developed for GDL fabrication exhibits excellent fuel cell performance using hydrogen/air at ambient pressure. The microstructure as seen under scanning electron microscope shows excellent surface morphology without any cracks. The membrane electrode assembly (MEA) with PUREBLACK® Carbon based GDLs shows power density as high as 0.55 W/cm^2 at 70 °C using hydrogen/air as reactants without any back pressure.

Keywords: PEM fuel cells; Membrane electrodes assembly; Gas diffusion layers; Electrochemical measurements; PUREBLACK® Carbon; Partially graphitized carbon black

1. Introduction

Proton exchange membrane fuel cells (PEMFCs) are attracting considerable amount of interest as alternative power sources for automotive, stationary and portable applications due to their higher power densities and environmental benefits. The major issues for the commercialization of PEMFC systems are the use of expensive components and limited performance and durability associated with the membrane electrode assemblies. The power density values are also reduced due to low catalyst activity and mass transport limitations mainly at the cathode. These shortcomings could be circumvented by developing an optimized MEA configuration designed using catalyst layer and gas diffusion layers [1,2]. GDLs play a significant role in H_2/air system performance at high current density region [3]. For optimal water management and performance, water retaining (hydrophilicity) and water expelling (hydrophobicity) properties of the GDLs have to be carefully balanced [4–6]. This helps avoid flooding when operating in 100% RH [5]. The hydrophilicity of the gas diffusion layers can also avoid drying of electrolyte in lower RH conditions [7]. Main functions of gas diffusion layers are distribution of reactants to the active site of electrode (pore size as well as porosity distribution), management of water supplied and/or generated and for the enhancement of electrical contact between the electrode and the bipolar plates [8,9]. Hence the necessary properties of gas diffusion layers are good gas diffusion properties with suitable water and air permeability, good electronic conductivity, crack free surface morphology and high mechanical integrity and enhanced oxidative stability [10–17].

Recently, Barsukov et al. have reported the use of PUREBLACK® Carbon as new and efficient conducting matrix in lithium-ion battery, and a number of other

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electrochemical cell configurations [18–20]. At the Arizona State University's Polytechnic campus (ASU-Poly), a high power MEA has been developed using a new type of graphitized nano-carbon, known as PUREBLACK® Carbon (Superior Graphite) for direct hydrogen fuel cells by functionally graded components in the MEAs. The results reported in here, highlight the electrochemical characteristics of PUREBLACK® Carbon in gas diffusion layers for PEM fuel cells for the first time.

2. Experimental

Gas diffusion layers were fabricated with teflonized non-woven carbon paper (P50T, Ballard Applied Materials) as a substrate. In order to fabricate the micro-porous layers, slurry of carbon with PTFE dispersion was prepared by ultrasonication followed by magnetic stirring. Hydrophobic characteristic of the micro-porous layers made from the graphitized carbon black grade PUREBLACK 205-110 Carbon (available from Superior Graphite Co., Chicago, IL, USA) was provided by T30 Teflon suspension (Dupont). The carbon loading on the micro-porous layer was approximately 3 mg/cm^2 and the PTFE content was 30 wt%. Heat treatment was carried out by sintering the GDLs at 350 °C under vacuum for about an hour. For comparison purpose GDLs were also fabricated with a well known Vulcan XC-72R in a similar procedure. Nano-fibrous type carbon (Showa Denko) was mixed with PUREBLACK® Carbon to provide improved mechanical strength and adhesion of the micro-porous layer with the macro-porous layer. The wetting characteristics (contact angle) of the GDLs were measured by ramé-hart Advanced Automated Goniometer using a mixture of methanol and water. Catalyst coated membranes with 5 cm^2 geometrically active area electrodes were fabricated by using 50 wt% Pt on carbon catalyst (Tanaka TEC1050E) by a micro-spray method on Nafion-112 membrane. The catalyst loadings on both anode and cathode sides were about 0.5 mg Pt/cm^2, respectively. The surface morphology of the GDL samples was examined by JEOL JSM-5900LV scanning electron microscope. The robustness of the micro-porous layer and also the adhesion of the micro-porous layer to the macro-porous substrate were evaluated by subjecting the GDL to ultrasonic vibration. The GDLs and the CCM were not hot-pressed but assembled by just sandwiching inside the test cell (Fuel Cell Technologies). Gas sealing was carried out using silicone coated fabric materials (Performance Plastics, CF1007) and with a uniform torque of 40 lb in. [21]. Linear sweep voltammetry (LSV) and cyclic voltammetry were carried out using Autolab Potentiostat/Galvanostat PG50 for measuring gas cross over and electrochemically active surface area (ECA) of the MEAs, respectively. The test cell was equilibrated for about 2 h with humidified hydrogen and nitrogen gases at 70 °C before the voltage scanning for LSV and CV measurements. Single cell fuel cell performance was evaluated using Fuel Cell Technologies Test Station, at 70 °C with H_2/air as well as H_2/O_2 under ambient pressure by galvanostatic polarization. The relative humidity of the reactant gases were maintained at 100% by controlling the humidity bottle temperatures.

3. Results and discussion

Figs. 1(a) and (b) show the high resolution transition electron microscope images of the new graphitized carbon (PUREBLACK® 205-110 Carbon, Superior Graphite). It is evident from Fig. 1(a) that this new form of nano-sized carbon exists in chain structure. Fig. 1(b), taken at a higher magnification, depicts presence of at least three phases in a single particle of PUREBLACK® Carbon.

Thus, rather thick, fully graphitic layer forms an outer shell of the particle. Parallel stacking of individual graphene layers is typical for this part of the carbon structure. This outer shell is being formed during the process of graphitization heat treatment of precursor carbon black material and is associated with exposure of precursor's

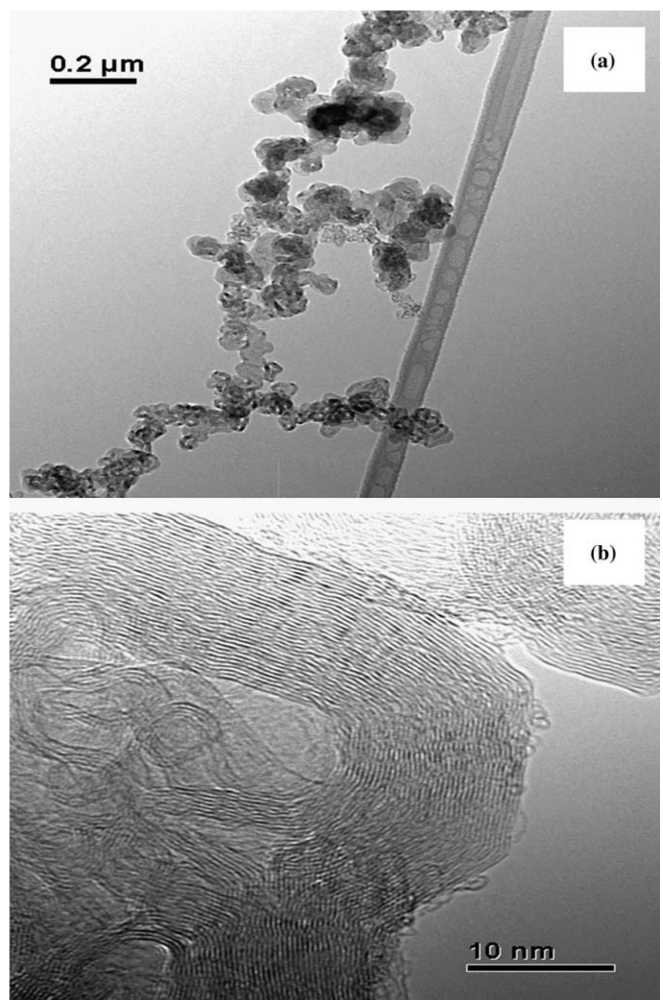

Fig. 1. Transmission electron micrographs of PUREBLACK® Carbon: (a) low magnification showing the chain structure and (b) high magnification showing well defined graphene layers of its graphitic structure (courtesy: Superior Graphite/Columbian Chemicals Co.).