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WHITE PAPER

SIGRACET® Gas Diffusion Layers for PEM Fuel Cells, Electrolyzers and Batteries

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SIGRACET® gas diffusion layer

Introduction

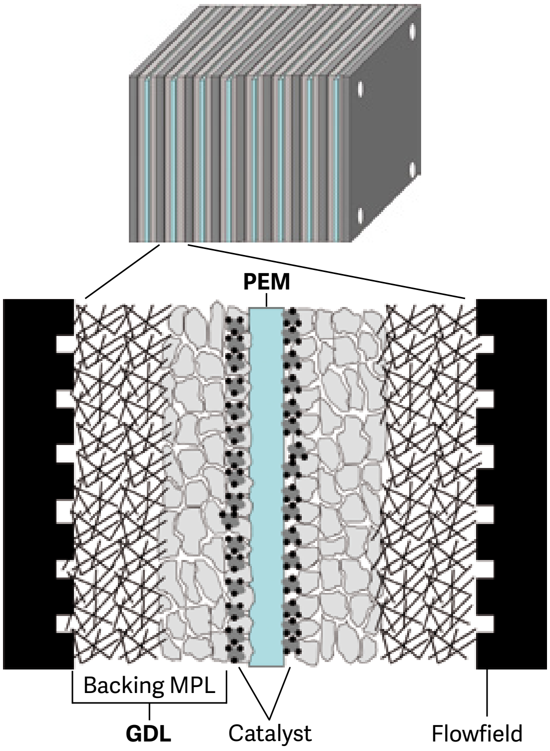
Gas diffusion layers (GDLs) are crucial components for proton exchange membrane fuel cells (PEMFCs), since they modulate all relevant transport processes (fuel, reaction products, electricity, heat) [1 – 2].

Figure 1 shows a typical setup of a single cell PEMFC. It consists of two flowfields, two GDLs, catalyst layers and the proton exchange membrane (PEM). Gas diffusion layers act as an interface between the flow fields (structural cell parts, millimeter-size features) and the electrocatalysts (reaction layers, nanometer-size features), directing the fuel to the active sites while removing heat and reaction products and electrically wiring the reaction layers with the current collectors.

Gas diffusion layers typically consist of a bilayer structure consisting of a macro-porous backing material (carbon fiber paper) and a micro-porous, carbon-based layer (MPL). The fibrous backing material governs the mechanical properties of the GDL (behavior upon compression, bending and shear strength) and also impacts the thermal and electric parameters.

Its hydrophobic properties and its microstructure have a significant effect on the water management via the capillary pressure-saturation relationship. Micro-porous layers are additional mediators of the water management of PEMFCs where pore size distribution, type of carbon and PTFE load can be adjusted to optimize water management under the prevalent operating conditions.

Additionally, the MPL facilitates catalyst deposition and effectively protects the proton exchange membrane against perforation by the carbon fibers.

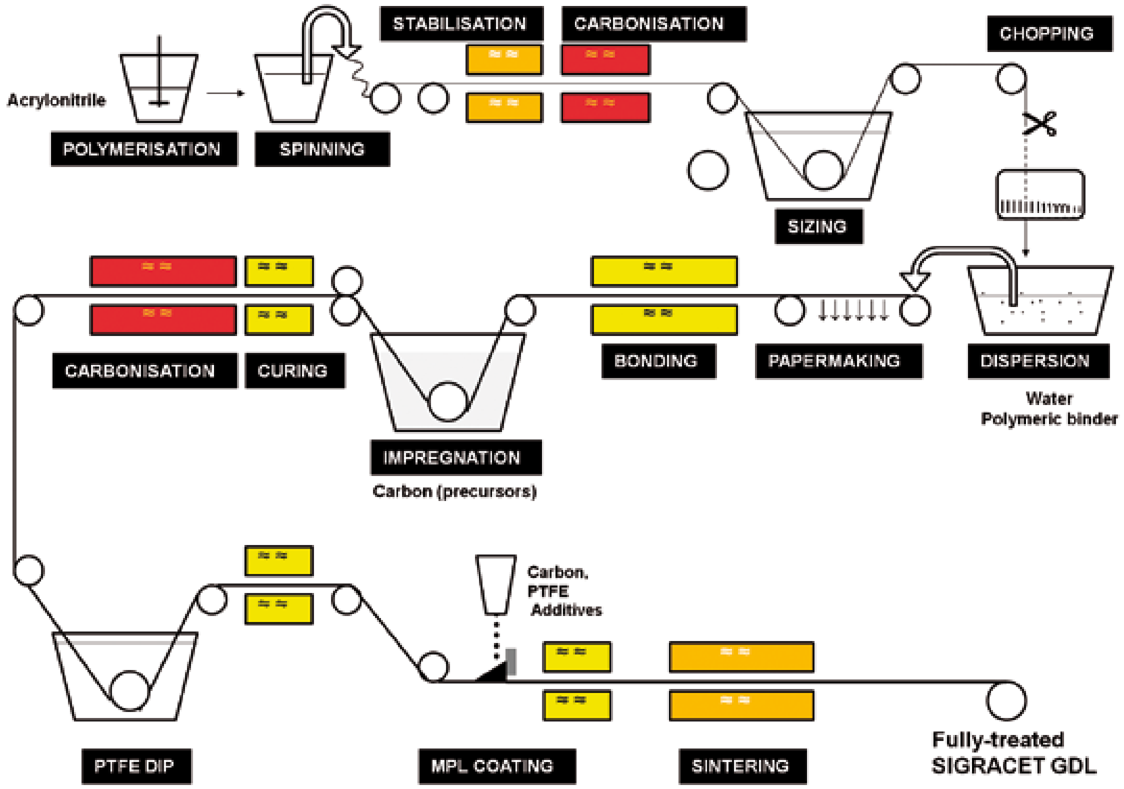


↑ ***Figure 1: Structure of a PEMFC single cell***

Manufacturing Process

Gas diffusion electrodes can be manufactured by depositing catalysts onto GDLs. Carbon paper-type (prepared by wet-laying of chopped PAN-based carbon fibers) gas diffusion layers are the preferred solutions since they can be manufactured at high volumes (scalability) and low thickness.

Chopped carbon fibers are processed to a primary carbon fiber web using a papermaking (wet-laying) technology and subsequent thermo bonding. The raw paper is then impregnated with carbonizable resins (carbonizable resins with optional addition of carbon fillers), cured and recarbonized/graphitized. (Figure 2)



↑ ***Figure 2: Manufacturing process of SIGRACET*** *(carbon paper-based)* ***gas diffusion layers***

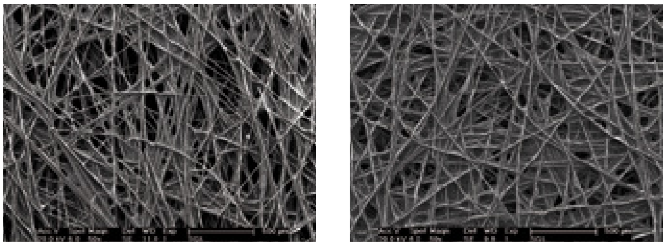
This procedure serves to adjust the porosity and to enhance electric and thermal conductivity. Figure 3 shows two GDL backings with different filler content which are the base for the finishing processes hydrophobic treatment with PTFE and coating with a micro-porous layer (MPL).

Sintering (thermal annealing) is applied in order to bond the substrate/MPL and to develop the full hydrophobic properties of the GDL. Proper selection of raw materials and additives ensures that the material is virtually free of heavy metals which are detrimental to fuel cell applications.

A loading of the substrate with 5 wt% PTFE has proven to be sufficient for obtaining a pronounced hydrophobicity (BA types). Nevertheless, higher loads up to 30 wt% are possible.

The standard microporous layer (C-type) is based on 77 wt% carbon black and 23 wt% PTFE. This MPL composition has been identified as the optimum composition in PEMFC tests (optimum level of porosity and hydrophobicity).

Mean pore sizes are in a range from 0.1 to 0.3 µm (mercury intrusion porosimetry) or 1.5 to 3 µm (calculated from capillary flow porometry). The hydrophobic treatment produces water repellent properties for the substrate and for the MPL (water contact angles by sessile drop method > 150 °).



← ***Figure 3: SEM images of carbon paper with different filler content (GDL backing with high porosity (left), low porosity (right))***

Physical Properties

Table 1 and 2 summarize the most important material properties of GDL backings (AA grades) and fully treated GDLs (BC grades). SIGRACET GDL grades comprise two porosity and thickness levels. This portfolio allows for a wide range of total pore volumes.

Table 1: Typical material data of SIGRACET® GDL backings (SIGRACET® AA grades)

Typical properties	Units	28 AA	29 AA	38 AA	39 AA
Thickness	μm	190	190	280	280
Area weight	gm^{-2}	55	40	75	50
Open porosity	%	82	88	82	89
Mean pore diameter	μm	39 – 44	48 – 51	25 – 29	42 – 44
TP area-specific resistance**	$m\Omega cm^2$	< 4	< 5	< 5	< 5
TP electric conductivity**	Scm^{-1}	4 – 5	3.5 – 4	5 – 6	4 – 5
IP electric conductivity (X/Y)**	Scm^{-1}	225/200	190/170	270/240	215/180
TP thermal conductivity	$Wm^{-1}K^{-1}$	0.5 – 0.6	0.4 – 0.5	< 0.4	< 0.3
IP permeability**	$10^{-12}m^2$	2 – 3	8 – 9	3 – 4	11 – 12
Bending stiffness (X/Y)	mNm	2.1/1.9	2/1.5	5.5/4.3	5.4/4.1
Compressibility (1 MPa)	%	13	31	12	33

Table 2: Typical material data of SIGRACET® GDLs (SIGRACET® BC grades)

Typical properties	Units	28 BC	29 BC	38 BC	39 BC
PTFE load of backing	wt%	5 ± 1	5 ± 1	5 ± 1	5 ± 1
PTFE content of MPL	wt%	23	23	23	23
Thickness	μm	235	235	325	325
Area weight	gm^{-2}	105	90	125	105
Open porosity	%	36 – 37	40 – 41	46 – 47	50 – 52
TP gas permeability (Gurley)*	$cm^3cm^{-2}s^{-1}$	0.5 – 0.7	0.9 – 1.3	0.2 – 0.4	1.0 – 1.5
TP gas permeability*	$10^{-12}m^2$	5 – 6	6 – 7	7 – 8	12 – 15
IP gas permeability**	$10^{-12}m^2$	1.4	1.9	2.3	2.7
TP area-specific resistance**	$m\Omega cm^2$	7.5 – 8.5	8.5 – 9.5	10 – 11	11 – 12
TP electric conductivity**	Scm^{-1}	2.4 – 2.7	2.0 – 2.3	2.5 – 2.8	2.0 – 2.2
IP electric conductivity (X/Y)**	Scm^{-1}	200/180	175/155	225/200	170/145
TP thermal conductivity*	$Wm^{-1}K^{-1}$	0.6	0.5	0.35	0.25
Compressibility (1 MPa)	%	13	18	13	30
Recovery (2.5 MPa)	%	65	61	65	54
Resiliency (2.5 MPa)	%	13	21	13	30

IP = in plane   TP = though plane   *uncompressed   **compressed with 1 MPa

Understanding the compression behavior of GDLs is important for minimizing contact resistances and to optimize water management in PEMFCs. Figure 4 and 5 show the effect of compression load on the thickness, the area-specific through-plane resistance and on the in-plane pressure drop.

In order to characterize the compressibility, the difference between uncompressed thickness (compression load of 5 psi) and thickness at a load of 1 MPa (which results in a compression to around 75 to 85 % of the initial thickness) can be used.

$$a_{1MPa}\,(\%) = \left[\frac{d_0 - d_{1MPa}}{d_0}\right] \cdot 100$$

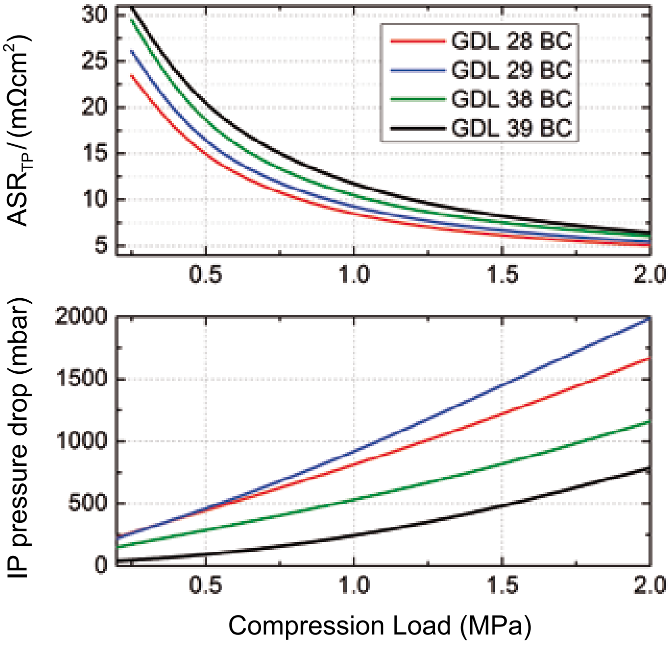
Since a GDL typically shows a certain fraction of elastic and plastic (inelastic) deformation, the recovery

$$rec_{2.5MPa}\,(\%) = \left[\frac{d_0^{2nd} - d_{2.5MPa}^{1st}}{d_0^{1st} - d_{2.5MPa}^{1st}}\right] \cdot 100$$

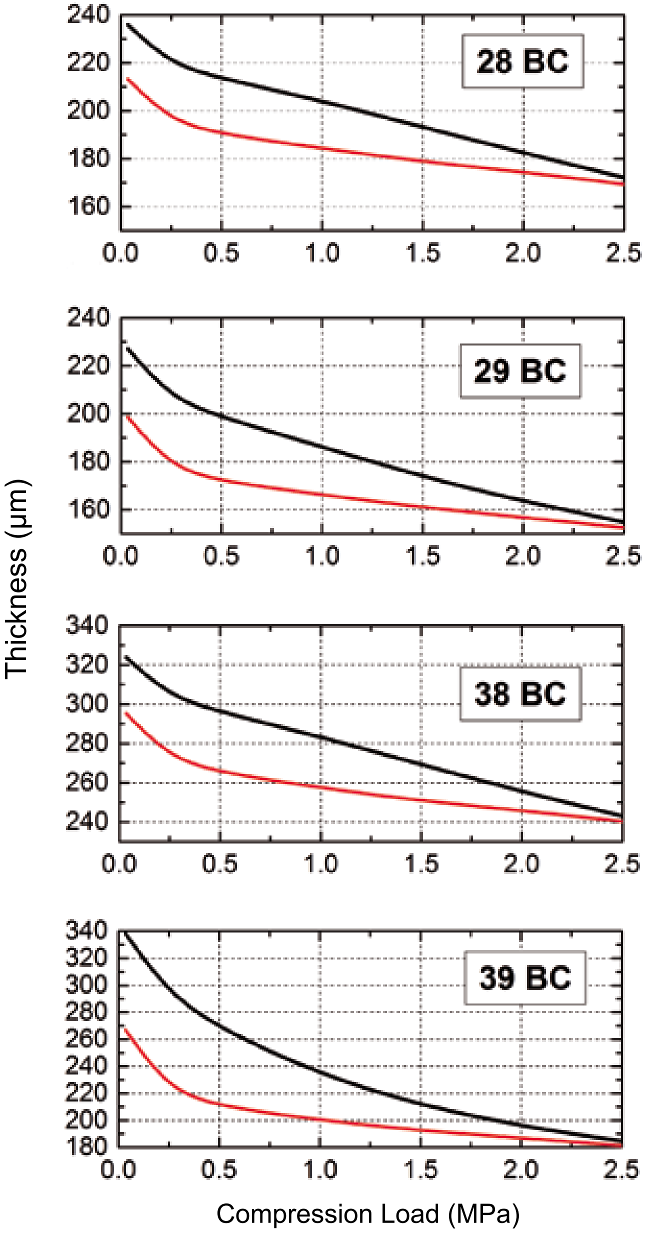
and resiliency of a GDL

$$res_{2.5MPa}\,(\%) = \left[\frac{d_0^{2nd} - d_{2.5MPa}^{1st}}{d_0^{1st} - d_{2.5MPa}^{1st}}\right] \cdot 100$$

constitute additional metrics for the compression behavior of GDLs.



↑ ***Figure 5:*** ***Area-specific through-plane resistance and in-plane pressure drop of SIGRACET GDL grades as a function of applied compression load***



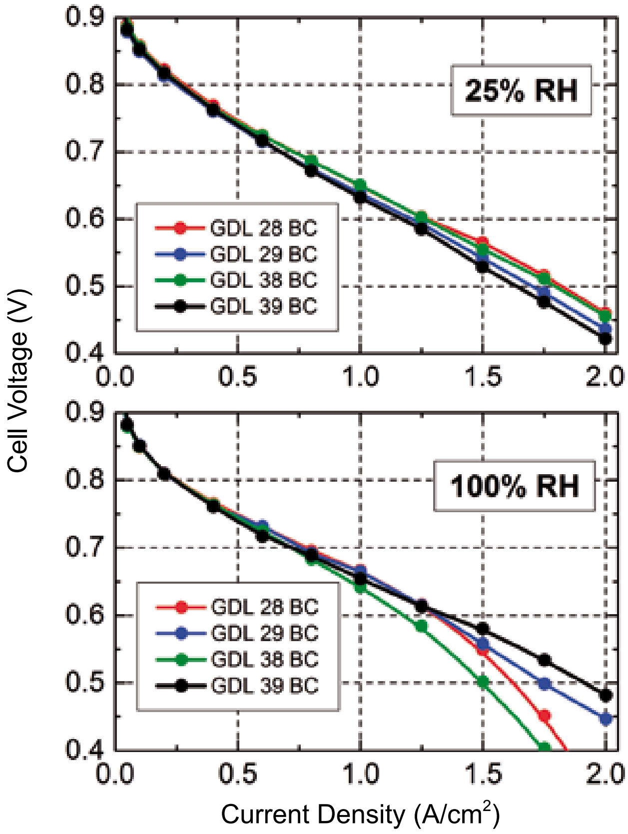
↑ ***Figure 4:*** **Compression plots of SIGRACET GDLs**
(first (black curve) and second (red curve) compression cycle)

Electrochemical Properties

GDLs are effective in supporting the water management in PEM fuel cells. Hence, proper choice of the GDL type is favorable to obtain the optimum cell performance. Figure 6 shows the typical PEMFC single cell performance of different GDLs under dry (25 % relative humidity (RH)) and wet (100 % RH) operating conditions.

As evident in Figure 6, the GDL platforms 28 and 38 are preferable for dry operation since the denser backing is preventing dehydration of the proton exchange membrane. Similarly, GDL 38 BC is recommended for high temperature PEM fuel cells (HT-PEMFCs) since it prevents leaching of phosphoric acid from PBI membranes.

By contrast, GDL 29 and 39 are recommended if high gas diffusivity is needed (predominantly wet operation, high current densities or low pressure).



→ ***Figure 6: Polarization curves of single cells*** *(25 cm^2)* ***using different SIGRACET GDLs under dry*** *(25 % RH)* ***and wet*** *(100 % RH)* ***operating conditions*** *(temperature 80 °C, 1.5 bar, stoichiometry H_2/air 1.5/2.5, CCM with 18 µm membrane, 0.5 mg/cm^2 Pt)*

The following Table 3 presents a recommendation of different SIGRACET GDL platforms for specific PEMFC types. This has been based on long-term field observations of the PEMFC industry. Further PEMFC application data of SIGRACET GDLs can be found in [8 – 11].

Table 3: Preferred SIGRACET® grade for various applications

Applications	GDL 28	GDL 29	GDL 38	GDL 39
	200 µm	200 µm	300 µm	300 µm
	Low porosity	High porosity	Low porosity	High porosity
PEMFC stationary	•		••	
PEMFC automotive	•	••		
PEMFC portable				•
HT-PEMFC			•	
DMFC		•		•
PEM electrolysis		•		••

Different modifications of finishing treatments could be used for further tailoring of PEMFC performance. For instance, various PTFE load of the backing (5 wt% – 20 wt%) and in the MPL [3] and MPL with carbon blends [5 – 7]. The following MPLs types are available (Table 4).

Table 4: Available MPL types

MPL types	Features
C	**Well established MPL – suitable for a variety of operating conditions**
B	Low loading MPL for enhanced mass transport

C-type MPL is a widely established industrial standard which is characterized by a low amount of cracks and which can be used for a variety of conditions. The B-type MPL shows better performance under wet conditions and high current densities.

Composite MPLs based on carbon nanotubes (MWCNT) and carbon black or graphite have reproducibly demonstrated excellent PEMFC performance [5 – 7], but still need further refining with respect to cost-efficient manufacturing.

Non-Fuel Cell Applications

Given its high conductivity and surface area, gas diffusion layers can inherently be used in related applications such as microbial fuel cells, PEM electrolysis, metal-air batteries, or redox flow batteries. The following Table 5 presents a selection of non-fuel cell applications and the recommended SIGRACET grades.

Conclusions

Gas diffusion layer technology has attained a high level of maturity. Nevertheless, the complex interactions among various cell components constantly require a design matching of the GDL with adjacent materials and cell operation strategy. Such an optimization is only facilitated by detailed feedback with respect to MEA/cell/stack performance.

Table 5: Selection of non-fuel cell applications and recommended SIGRACET® grades

Applications	Material applied as	Recommended grade(s)
Redox flow batteries	Porous electrode for zero-gap cell design	GDL 39 AA/38 AA
Metal-air batteries	Cathode support (for GDE)	GDL 39 AA/BA/BC
Microbial fuel cells	Electrode support	GDL 39 AA/BC
PEM electrolysis	Cathode support	GDL 39 AA/BA/BC

References

[1] **Diffusion media and characterization.** M. F. MATHIAS, J. ROTH, J. FLEMING, W. LEHNERT in: W. VIELSTICH, H. A. GASTEIGER, A. LAMM (Eds.) Handbook of Fuel Cells, Vol. 3, **2003,** Chapter 6.; Wiley, New York, pp 517-537

[2] **Ex-situ characterisation of gas diffusion layers for proton exchange membrane fuel cells.** A. EL-KHAROUF, T. J. MASON, D. J. L. BRETT, B. G. POLLET, J. Power Sources **2010,** 218, 393-404

[3] **Effect of polytetrafluoroethylene treatment and microporous layer-coating on the electrical conductivity of gas diffusion layers used in proton exchange membrane fuel cells.** M. S. ISMAIL, T. DAMJANOVIC, D. B. INGHAM, M. POURKASHANIAN, A. WESTWOOD, J. Power Sources **2010,** 195, 2700-2708

[4] **On the through-plane permeability of microporous layer-coated gas diffusion layers used in proton exchange membrane fuel cells.** M. S. ISMAIL, D. S. BORMAN, T. DAMJANOVIC, D. INGHAM, M. POURKASHANIAN, Int. J. Hydrogen Energ. **2011,** 36, 10392-10402.

[5] **Enhancement of proton exchange membrane fuel cell performance by doping of microporous layers of gas diffusion layers with multiwall carbon nanotubes.** R. SCHWEISS, M. STEEB, P. M. WILDE, T. SCHUBERT, J. Power Sources **2012,** 220, 79-83

[6] **Degradation of gas diffusion layers in PEM fuel cells during drive cycle operation.** R. MUKUNDAN, J. DAVEY, K. RAU, D. LANGLOIS, D. SPERNJAK, K. ARTYUSHKOVA, R. SCHWEISS, R. L. BORUP, ECS Trans. **2013,** 58, 919-926

[7] **The importance of carbon materials in micro-porous layer in gas diffusion layers for proton exchange membrane fuel cells.** R. SCHWEISS, O. OETTINGER, TANSO **2015,** 268, 131-13

[8] **The effect of materials on proton exchange membrane fuel cell electrode performance.** B. MILLINGTON, S. DU, B. G. POLLET, J. Power Sources **2011,** 192, 9013-9017

[9] **Gas diffusion layer materials and their effect on polymer electrolyte fuel cell performance – ex-situ and in-situ performance.** A. EL-KHAROUF, N. V. REES, R. STEINBERGER-WILCKENS, Fuel Cells **2014,** 14 , 735-741

[10] **Feasibility of in-plane GDL structuration: Impact on current density distribution in large-area Proton Exchange Membrane Fuel Cells.** L. JABBOUR, C. ROBIN, F. NANDJOU R. VINCENT, F. MICOUD, J.-P. POIROT-CROUVEZIER, J. D'ARBIGNY D M. GERARD, J. Power Sources **2015,** 299, 380-390

[11] **Understanding flexural, mechanical and physico-chemical properties of gas diffusion layers for polymer membrane fuel cell and electrolyzer systems.** S.R. DHANUSHKODI, F. CAPITANIO, T. BIGGS, W. MÉRIDA, Int. J. Hydrogen Energ. **2015,** 40, 16846-16859