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Powering up fuel cells

Our gas diffusion layer (White Paper)

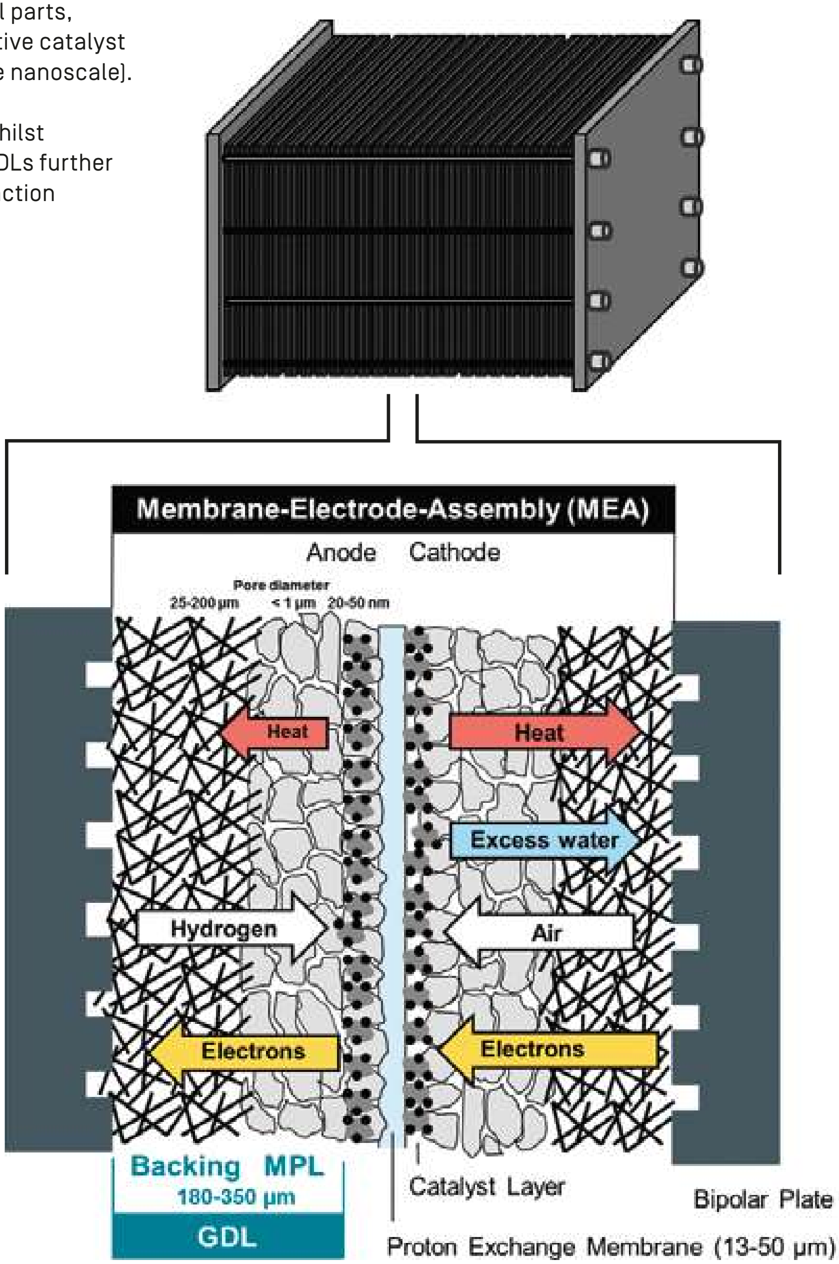
SIGRACET®

GDL and PEM fuel cells

Gas diffusion layers (GDLs) are vital components in PEM fuel cells modulating all relevant transport processes comprising fuel, oxidants, reaction products, electricity and heat.

Gas diffusion layers serve as a functional interface between the gas distribution compartments (structural cell parts, macroscopic scale) and the electrochemically active catalyst layers (reaction layers, processes occurring at the nanoscale).

GDLs direct fuel and oxidants to the active sites whilst dissipating heat and purging reaction products. GDLs further provide the electrical connection between the reaction layers and the current collectors.



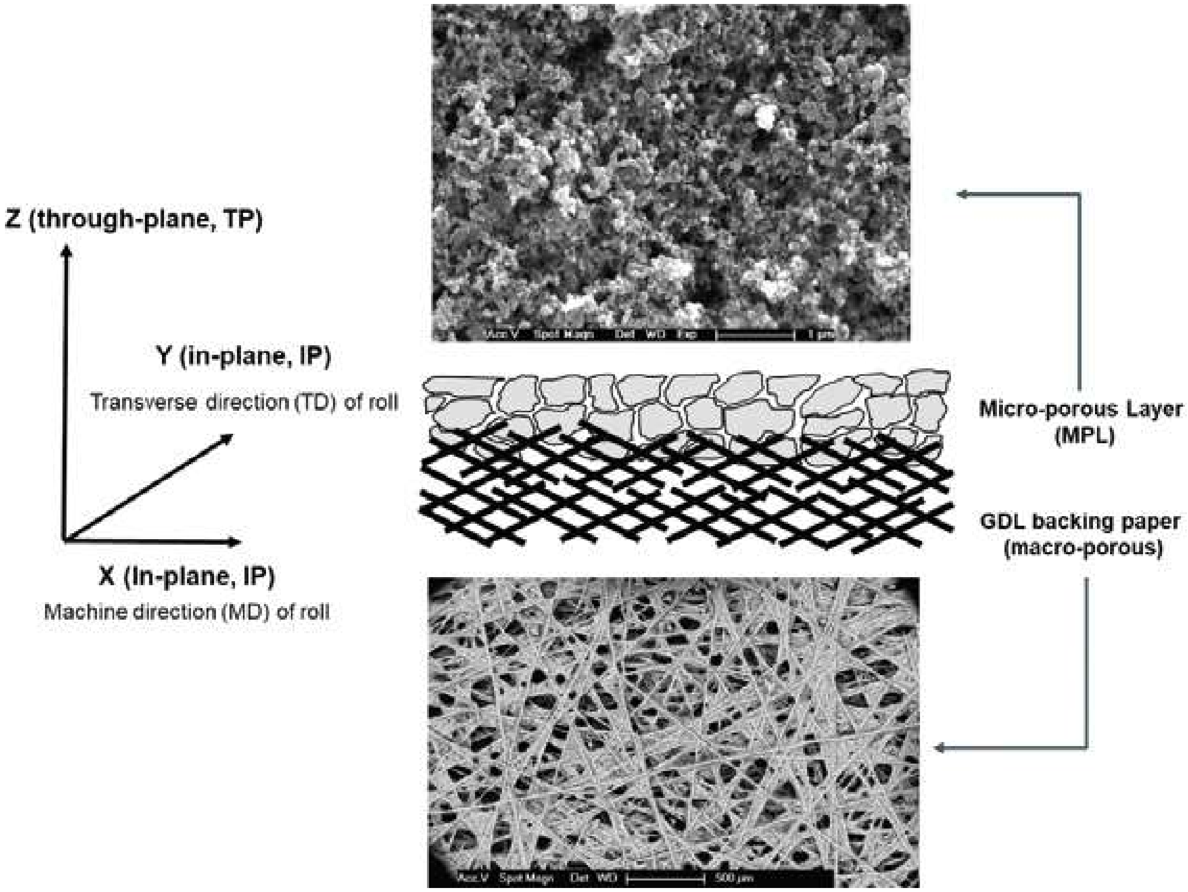
↑ Sketch of a single cell fuel cell with gas diffusion layers (GDL)

Gas diffusion layers are typically designed as a bilayer structure consisting of a macro-porous backing material (carbon fiber paper support) 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, etc.), whereas the MPL ensures intimate contact to the catalyst layers, protects the delicate proton exchange membrane against perforation and plays an active role with respect to the water management during operation.

There is consensus in the scientific community that the heterogeneous porosity brought about by this structure (hydrophilic/hydrophobic and various pore sizes) is advantageous for fuel cell performance.

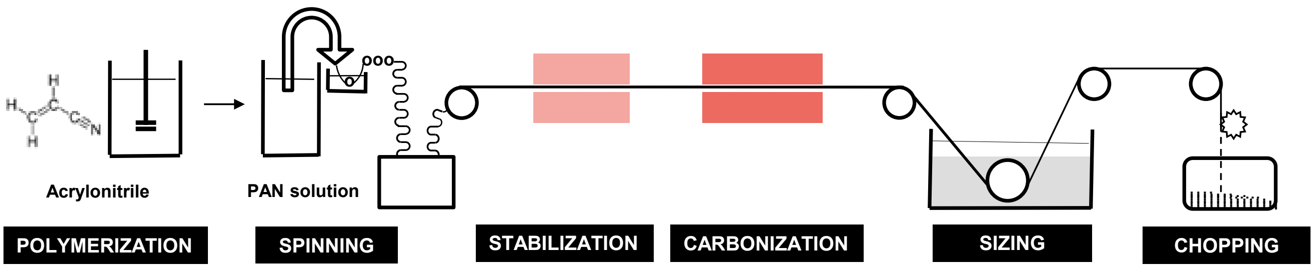
Hydrophobic properties in the backing and the MPL are maintained by adding defined amounts of polytetrafluoroethylene (PTFE) to both sublayers. Various types of carbon particles (carbon blacks, graphite) can be used in the MPL to produce different levels of hydrophobicity. Furthermore, the MPL can be used as substrate to deposit catalyst particles for the manufacture of gas diffusion electrodes (GDEs).



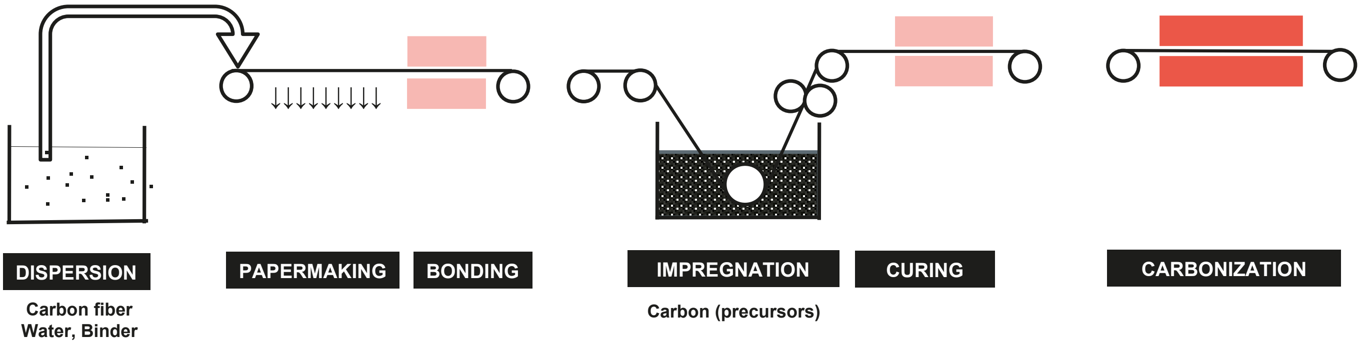
↑ Sketch of the bilayer structure of gas diffusions layers

Carbon paper-type (prepared by wet-laying of chopped PAN-based carbon fibers) gas diffusion layers are the preferred solution since they can be manufactured in high volumes (scalability) and low thickness.
The following graphics show the entire value chain of GDL manufacturing. All commercially available GDL materials to date are based on carbon fibers derived from polyacrylonitrile. PAN (co)polymers processed into precursor fibers by wet-spinning. Subsequent stabilization and carbonization yield high tensile (HT) carbon fibers which are sized and chopped to enable further processing in state-of-the-art papermaking equipment.
A primary carbon fiber web is laid in a papermaking process with subsequent thermo-bonding. Next, the obtained raw paper is impregnated with thermoset resins (with optional addition of carbon fillers), cured and re-carbonized/graphitized.
This serves to enhance the mechanical stability and conductivity as well as to adjust the desired porosity level. Finishing of GDL comprises hydrophobic treatment of the substrate with PTFE and coating with a microporous layer (MPL).

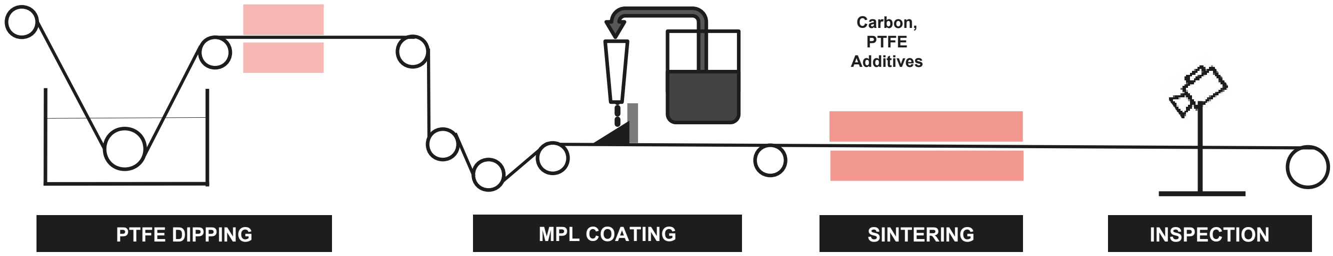
Manufacturing route of chopped carbon fibers



Manufacturing route of SIGRACET (carbon paper-based) gas diffusion layer backings



Finishing treatments of SIGRACET (carbon paper-based) gas diffusion layers



Material properties

High temperature treament processes allow for the manufacturing of materials with highest purity and excellent electronic conductivity. Porosity and mechanical properties can be adjusted by applying different portions of carbon matrix materials.

A loading with 5 % (w/w) PTFE of the substrate has proven to be sufficient for obtaining a pronounced hydrophobicity. Our MPLs typically contain 20 to 25 % (w/w) PTFE. This hydrophobic treatment of both sublayers produces water repellent properties (water contact angles > 130°) which prevent the highly porous carbon fiber backings from flooding and actively support the water management of the PEMFC.

Typical properties of fully-treated SIGRACET® GDL grades

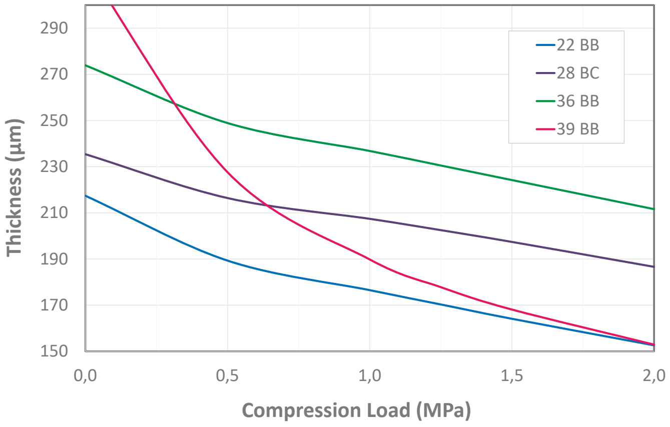
Material properties	Units	22 BB	28 BC	36 BB	39 BB
Basic parameters					
Thickness	µm	215	235	280	315
Area weight	$g\ m^{-2}$	70	105	105	95
Gas transport					
TP gas permeability	Gurley sec	1.2	4.5	3.0	1.5
TP gas permeability (1 MPa)	$10^{-12}\ m^2$	0.47	0.10	0.21	0.12
IP gas permeability**	$10^{-12}\ m^2$	2.8	0.9	1.8	8.40
Electronic resistance					
TP area-specific resistance (1 MPa)	$m\Omega\ cm^2$	< 10	< 11	< 12	< 13
IP electric resistance**	Ω mm	0.33	0.21	0.27	0.56
Heat transport					
TP thermal conductivity*	$Wm^{-1}K^{-1}$	0.30	0.38	0.43	0.20
Mechanical properties					
Bending stiffness (MD/TD)	N mm	1.5/0.9	1.7/1.2	3.6/3.2	3.5/2.9
Compressibility (5 psi → 1.0 MPa)	%	20	11	14	27
Compression set (0.6 MPa)	µm	12	9	10	15
Compression set (1.0 MPa)	µm	18	12	14	30
Compression set (1.5 MPa)	µm	26	15	20	37
Compression set (2.0 MPa)	µm	30	17	22	60
Tensile strength (MD/TD/TD)	MPa	6.9/4.6	6.6/5.1	8.5/8.1	7.7/4.9
Surface properties					
Water contact angle (MPL)	°	> 130	> 130	> 130	> 130
Roughness R_a (MPL side)	µm	7.2	6.4	5.8	7.0
Chemical properties					
Impurities (Fe, Co, Ni)	ppm	< 10	< 10	< 10	< 10

* uncompressed, ** van der Pauw method

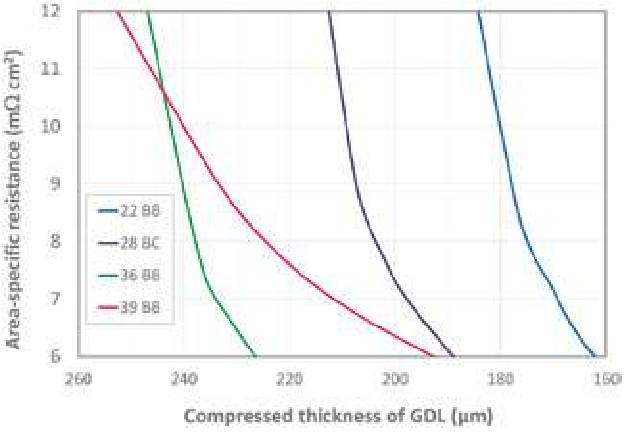
Effects of compression on GDL properties

In PEMFC stacks, the membrane electrode assemblies are compressed in order to ensure intimate contact to the bipolar plates. The compressibility is governed by the two GDLs contained in the MEA. Hence, the behavior of the GDLs is crucial for stack sealing and performance. The following figures show the compression curves and the effects of compression on the in-plane gas permeability and the area-specific resistance for all SIGRACET grades.

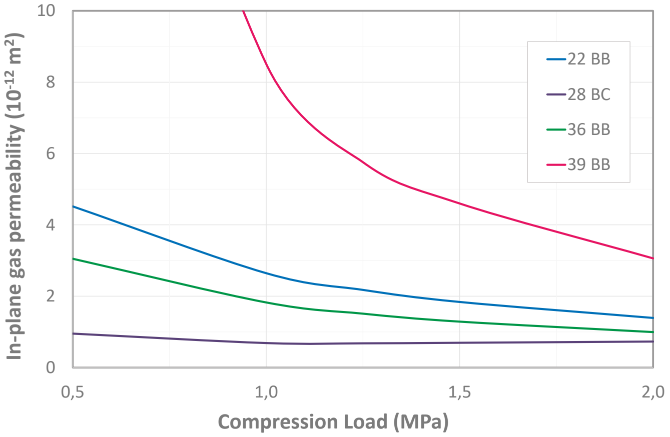
Compression plots of SIGRACET GDLs



Area-specific resistance of different SIGRACET GDLs versus compressed thickness



Typical In-plane gas permeability of SIGRACET GDLs as a function of the compression load



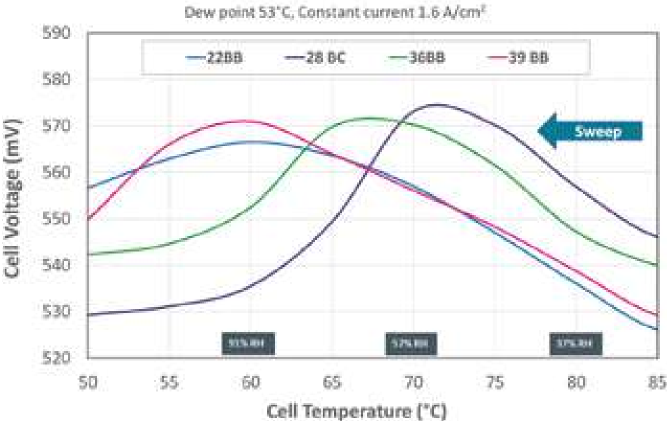
Application in PEM fuel cells

GDLs are effective in supporting the water management in PEM fuel cells. Hence, proper selection of the best suited GDL type is key to obtain optimum cell performance. The figure shows results obtained from a single cell with 25 cm² active area using graphite plates with 5-serpentine flow channels and a commercial CCM with a 15 µm PEM (0.5 mg/cm² Pt). Compression load onto the GDL/MEA was kept constant at 1 MPa.

The following table presents a recommendation of different SIGRACET GDL platforms for specific types/operating conditions and is based on long-term field observations within the PEMFC industry.

The novel B-type MPL introduced in 2015 enables enhanced gas transport at high current density. Recent findings in our lab and other studies suggest that MEAs containing non-symmetric GDLs can be advantageous for fuel cell performance under certain conditions.

Steady-state single cell tests (RH/temperature sweep). Cell voltages (at 1.6 A/cm²) of single cells assembled with different SIGRACET GDLs



Preferred SIGRACET® GDL grades for various applications

Application	GDL 22 215 µm High porosity	GDL 28 235 µm Low porosity	GDL 36 280 µm Medium porosity	GDL 39 315 µm High porosity
PEMFC stationary		●	●	
PEMFC automotive	●●	●	●●	
PEMFC portable				●
HT-PEMFC			●●	
PEM electrolysis	●			●

● refers to the frequency of use

Applications beyond PEMFCs

Given their high conductivity and surface area, gas diffusion layers can inherently be used in PEMFC-related applications such as microbial fuel cells, PEM electrolysis or metal-air batteries.

Summary

Gas diffusion layer technology has attained a high level of maturity. Our GDL portfolio is suitable for a variety of operating conditions and applications. Nevertheless, the complex interactions among various cell components constantly require a design matching process of the GDL with adjacent materials and cell operation strategy. Such an optimization is only facilitated through a holistic analysis of MEA/cell/stack performance.