Thermal Conductivity Analysis of Carbon Paper – Optimizing Fuel-Cell Gas Diffusion Layers

Jinyan Li, Applications Laboratory Shanghai, and Dorothea Stobitzer, Applications Laboratory Selb

Proton Exchange Fuel Cell (PEMFC)

Proton Exchange Membrane Fuel Cell (PEMFC), as an emerging low-temperature fuel cell, has the advantages of high efficiency, low operating temperature and zero emission, which is one of the main development directions of new green energy.

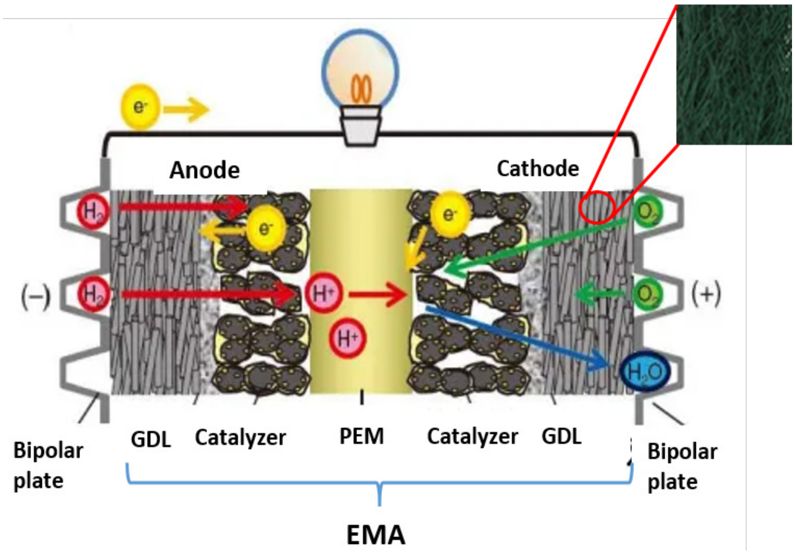
The core component of PEMFC is the Membrane Electrode Assembly (MEA), which consists of two Gas Diffusion Layers (GDL), two catalytic layers and a proton exchange membrane.

The reaction principle of a PEMFC fuel cell is shown in figure 1. The PEMFC single cell consists of an EMA (anode, cathode and proton exchange membrane) and bipolar plates. The anode is the place where the oxidation of hydrogen fuel occurs, and the cathode is the place where the redox occurs. Both poles contain catalysts to accelerate the electrochemical reaction of the electrodes, and platinum/carbon or platinum/ruthenium are generally used as the electrocatalysts. The proton exchange membrane acts as the electrolyte; hydrogen or purified reformed gas is the fuel; air or pure oxygen is the oxidant; and the graphite or the surface-modified metal plate with the gas flow channel is the bipolar plate. Hydrogen and oxygen with a certain humidity and pressure enter the anode and cathode, respectively, and reach the interface between the catalyst layer and the proton exchange membrane through the gas diffusion layer (carbon paper in the figure), where oxidation and reduction reactions take place under the action of the catalyst.

Anode: $H_2 \rightarrow 2H^+ + 2e^-$

Cathode: $½\,O_2 + 2H^+ + 2\,e^- \rightarrow H_2O$

Total battery reaction: $H_2 + ½\,O_2 \rightarrow H_2O$



1 Schematic diagram of a single cell of a fuel cell (including membrane electrodes and bipolar plates)

NGB · Application Note 320 · EN · 0824 · Technical specifications are subject to change.

NETZSCH-Gerätebau GmbH
Wittelsbacherstraße 42 · 95100 Selb · Germany
Phone: +49 9287/881-0 · Fax: +49 9287/881505
at@netzsch.com · www.netzsch.com

At the anode, hydrogen gas reacts electrochemically to form hydrogen ions and electrons. The hydrogen ions are then conducted to the cathode through a proton exchange membrane (the unique properties of the proton exchange membrane allow only hydrogen ions to pass through) and the electrons reach the cathode through an external circuit, where the hydrogen ions, electrons and oxygen react to form water. The generated water is discharged from the cathode outlet as water vapor or condensate along with excess oxygen.

Gas Diffusion Layer (GDL)

The Gas Diffusion Layer (GDL) is located at both ends of the membrane electrode, which is one of the important components of the fuel cell; its role includes supporting the proton exchange membrane, coating the catalyst, connecting the membrane electrode with the bipolar plate, etc.

The GDL material needs to have the following points in terms of performance:

1. Because the GDL is between the bipolar plate and the catalyst layer, the electrochemical reaction (i.e., the current density) is very high – there is a high degree of galvanic corrosion – so the GDL material must have corrosion resistance.
2. The GDL material – as hydrogen /oxygen or methanol/air diffusion to the catalyst layer reaction medium – must be a porous, breathable material.
3. The GDL material plays the role of a current conductor and must be highly conductive material.
4. The battery reaction is exothermic; the GDL material must be a high thermal conductivity material; heat dissipation must be timely to avoid local overheating caused by the proton exchange membrane breakage.
5. The GDL material should have high hydrophobicity to avoid damage to the catalyst layer caused by the water generated by the battery reaction

Carbon Fiber Paper

Carbon fiber paper (referred to as carbon paper) is manufactured from short-cut carbon fibers as a raw material; this has a fiber porous structure in microscopic, which can establish effective channels for gas and water conduction. At the same time, carbon paper has the advantages of light weight, a flat surface, corrosion resistance and uniform porosity. In addition, the high strength of carbon paper can bring protection for the installation and use of PEMFC batteries, stabilize electrode structure and improve battery life. The carbon paper manufacturing process is mature, with stable performance; therefore, carbon paper has become the mainstream choice for gas diffusion layer materials in the membrane electrode. The membrane electrode with carbon paper as the gas diffusion layer is shown in Figure 1. Due to fiber orientation arrangement in the preparation process for carbon paper, the carbon paper itself has various anisotropies.

Given that thermal conductivity is one of the important indexes of GDL materials, in this work, thermal conductivity tests were carried out on a carbon paper sample by means of the NETZSCH LFA *HyperFlash*®. In this test, the LFA 467 was used to test the thermal diffusivity of the carbon paper sample in horizontal and vertical directions respectively, and DSC was used to test the specific heat capacity of the carbon paper sample. The thermal conductivity of the sample was obtained by multiplying the thermal diffusivity, the specific heat capacity and the density (at room temperature) of the sample.

NGB · Application Note 320 · EN · 0325 · Technical specifications are subject to change.

NETZSCH-Gerätebau GmbH
Wittelsbacherstraße 42 · 95100 Selb · Germany
Phone: +49 9287/881-0 · Fax: +49 9287/881505
at@netzsch.com · www.netzsch.com

NETZSCH

Applications

Table 1 shows the results of the thermal conductivity test in the horizontal direction for this carbon paper sample (figure 2). The support used for this test is an in-plane sample holder (figure 3), which can be used to test the thermal diffusivity of high thermal conductivity thin film materials in the horizontal direction. It can be seen that the thermal diffusivity in the horizontal direction of the sample at 25°C and 100°C is 58.610 mm²/s and 50.122 mm²/s, respectively, and the thermal conductivity is 20.568 W/(m*K) and 21.794 W/(m*K), respectively.

Table 1 Results for thermal conductivity of carbon paper samples in horizontal direction.

Thermal Diffusivity - NETZSCH LFA Analysis

General information

Database :	carbon paper.mdb	**Operator :**	ljy
Instrument :	LFA 467	**Remark(mment) :**	---
Identity :	c4842	**Cp table :**	Carbon paper-Cp
Date :	09.10.2022	**Expansion table :**	dL_const
Material :	Carbon paper	**Diffusivity table :**	diff_const
Ref. density (20,0 °C) /(g/cm^3) :	0,501	**Furnace :**	LFA 467 Steel
Sample :	A	**Sample holder :**	In-plane (Outward Heat Flow) round/25.4mm
Type :	In-plane	**Lamp :**	LFA 467 Flash Lamp
Sample position :	A	**Furnace TC :**	E
Detection Area (Diameter)/mm :	14,0	**Sample TC :**	E
Filter/% :	0	**Sample Xp / Tn :**	4,00 / 4,00
Thickness (RT) /mm :	0,1890	**Furnace Xp / Tn :**	4,00 / 4,00
Diameter /mm :	25,200	**Calculation code :**	In-plane Isotropic + p.c./l/1-0-1
D0 /mm :	5,000	**Purge 1 MFC**	NITROGEN
D1 /mm :	9,500	**Purge 2 MFC**	NITROGEN
D2 /mm :	12,000	**Protective MFC**	NITROGEN
Sensor :	MCT		

Results

Shot number	Temperature °C	Model	Diffusivity mm^2/s	Uncertainty %	Conductivity W/(m*K)	Cp-table J/(g*K)	Laser voltage V	Pulse width ms
2	25,0	In-plane Isotropic(I)	58,653	0,2	20,583	0,700	250,0	0,15
3	25,0	In-plane Isotropic(I)	58,635	0,2	20,576	0,700	250,0	0,15
4	25,0	In-plane Isotropic(I)	58,664	0,2	20,586	0,700	250,0	0,15
5	25,0	In-plane Isotropic(I)	58,488	0,2	20,525	0,700	250,0	0,15
Mean:	**25,0**		**58,610**		**20,568**	**0,700**		
Std. Dev.:	**0,0**		**0,082**		**0,029**	**0,000**		
7	100,0	In-plane Isotropic(I)	50,046	0,3	21,758	0,868	250,0	0,15
8	100,0	In-plane Isotropic(I)	50,118	0,3	21,789	0,868	250,0	0,15
9	100,0	In-plane Isotropic(I)	50,148	0,3	21,808	0,868	250,0	0,15
10	100,0	In-plane Isotropic(I)	50,175	0,3	21,819	0,868	250,0	0,15
Mean:	**100,0**		**50,122**		**21,794**	**0,868**		
Std. Dev.:	**0,0**		**0,055**		**0,027**	**0,000**		

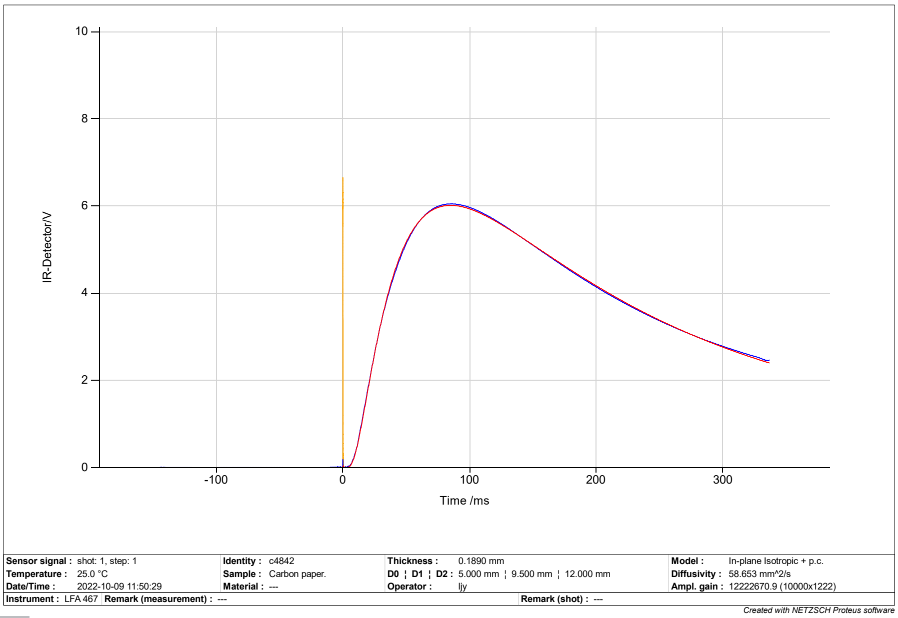
2 Photograph of the carbon paper sample

3 In-plane sampel holder

NETZSCH-Gerätebau GmbH
Wittelsbacherstraße 42 · 95100 Selb · Germany
Phone: +49 9287/881-0 · Fax: +49 9287/881505
at@netzsch.com · www.netzsch.com

Figure 4 shows the tested temperature rise curve, and it can be seen that the test curves (raw signal – blue) and the fitted curve (model evaluation – red) are in very good agreement.

Table 2 shows the results of the thermal conductivity test for this carbon paper sample in the vertical direction.



4 Temperature rise curve for the carbon paper samples tested in horizontal direction

Table 2 Temperature rise curve for the carbon paper samples tested in vertical direction

Thermal Diffusivity - NETZSCH LFA Analysis

General information

Database :	carbon paper.mdb	**Remark(mment) :**	---
Instrument :	LFA 467	**Cp table :**	Carbon paper-Cp
Identity :	c4842	**Expansion table :**	dL_const
Date :	24.10.2022	**Furnace :**	LFA 467 Steel
Material :	Carbon paper.	**Sample holder :**	Foil/25.4mm
Ref. density (20,0 °C) /(g/cm^3) :	0,501	**Lamp :**	LFA 467 Flash Lamp
Sample :	碳纸-垂直	**Furnace TC :**	E
Type :	Single layer	**Sample TC :**	E
Sample position :	B	**Sample Xp / Tn :**	4,00 / 4,00
Detection Area (Diameter)/mm :	3,7	**Furnace Xp / Tn :**	4,00 / 4,00
Filter/% :	0	**Calculation code :**	Standard + p.c./-/1-0-1
Thickness (RT) /mm :	0,1890	**Purge 1 MFC**	NITROGEN
Diameter /mm :	25,200	**Purge 2 MFC**	NITROGEN
Sensor :	MCT	**Protective MFC**	NITROGEN
Operator :	ljy		

Results

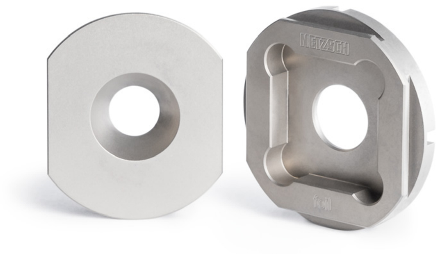
Shot number	Temperature °C	Model	Diffusivity mm^2/s	Uncertainty %	Conductivity W/(m*K)	Cp-table J/(g*K)	Laser voltage V	Pulse width ms
1	25,0	Standard(-)	7,476	1,4	2,623	0,700	200,0	0,01
2	25,0	Standard(-)	7,421	2,2	2,604	0,700	200,0	0,01
3	25,0	Standard(-)	7,478	1,4	2,624	0,700	200,0	0,01
4	25,0	Standard(-)	7,475	1,2	2,623	0,700	200,0	0,01
Mean:	**25,0**		**7,463**		**2,619**	**0,700**		
Std. Dev.:	**0,0**		**0,028**		**0,010**	**0,000**		
5	100,0	Standard(-)	6,387	1,3	2,777	0,868	200,0	0,01
6	100,0	Standard(-)	6,376	1,7	2,772	0,868	200,0	0,01
7	100,0	Standard(-)	6,419	1,7	2,791	0,868	200,0	0,01
8	100,0	Standard(-)	6,451	1,7	2,805	0,868	200,0	0,01
Mean:	**100,0**		**6,408**		**2,786**	**0,868**		
Std. Dev.:	**0,0**		**0,034**		**0,015**	**0,000**		

NGB · Application Note 320 · EN · 0325 · Technical specifications are subject to change.

NETZSCH-Gerätebau GmbH
Wittelsbacherstraße 42 · 95100 Selb · Germany
Phone: +49 9287/881-0 · Fax: +49 9287/881505
at@netzsch.com · www.netzsch.com

NETZSCH

The support used for this test was a foil sample holder (figure 5) which can be used to test the thermal diffusivity of thin film samples in the vertical direction. From the results, it can be seen that the thermal diffusivity in the vertical direction of the sample is 7.463 mm^2/s and 6.408 mm^2/s at 25ºC and 100ºC, respectively, and the thermal conductivity is 2.619 W/(m*K) and 2.786 W/(m*K), respectively. The thermal conductivity of the samples in the horizontal direction is significantly higher than that in the vertical direction, with obvious individual anisotropy. Because the sample has a porous fiber structure, there is a certain degree of light transmission when testing in the vertical direction.



5 Foil sample holder designed for thermal conductivity measurements in the thickness direction of thin films

Summary

In proton exchange membrane fuel cells, the gas diffusion layer serves as an important component of the membrane electrode, and its cost usually accounts for 20-25% of the cost of the membrane electrode.

Industry analysis predicted that the market size for global gas diffusion layer materials will reach USD 3.34 billion by 2024. Carbon paper, as the preferred material for the gas diffusion layer, has a very promising future for industry development in China. Thermal conductivity is one of the important indicators for carbon papers. With the NETZSCH Flash Thermal Conductivity Analyzer LFA 467 and its in-plane holder and foil sample holder, the thermal conductivity of carbon paper samples in the horizontal and vertical directions can be tested accurately and conveniently.

NGB · Application Note 320 · EN · 0325 · Technical specifications are subject to change.

NETZSCH-Gerätebau GmbH
Wittelsbacherstraße 42 · 95100 Selb · Germany
Phone: +49 9287/881-0 · Fax: +49 9287/881505
at@netzsch.com · www.netzsch.com