PERFORMANCE ANALYSIS OF DIRECT METHANOL FUEL CELLS BY COATING DIFFERENT PROPORTIONS OF CATALYSTS ONTO FUEL CHANNELS

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In this study, different proportions of catalysts, including Platinum (Pt), active carbon and Selenium (Se), were coated onto anode and cathode channels composed of PDMS (polydimethylsiloxane) to promote the fuel decomposition reaction in the fuel channels and to further enhance the output of the DMFCs under various operating temperatures. The experimental results indicated that under identical operating conditions, the performances of DMFCs with catalysts coated onto their channels are always superior to that of DMFCs without an added catalyst. The results indicate that a critical catalyst loading value exists for every catalyst. When the amount of catalyst added is less than this critical value, the output of the DMFCs can be greatly enhanced by increasing the proportion of the catalyst added to the fuel channels. However, when the amount of catalyst added exceeds the critical value, efficiency enhancements are no longer apparent. Suitable coating weight percentage for every catalyst was recommended. The corresponding recommendation values for catalysts of Pt, active carbon and Se are 0.06%, 0.29% and 0.29%, respectively, under the investigated operating conditions. The maximum power density increment of 182.3% can be attained in the case with 0.29% Se catalyst loading at an operating temperature of 30℃.

1. Introduction

The direct methanol fuel cell (DMFC), which utilizes a methanol solution as a fuel, has been considered a promising power source for portable electronic devices. Methanol has a high energy density and specific, superior chemical stability, which are important properties for transport and storage. Thus, compared with other fuel cell systems, the DMFC is a simple and compact system, as well as a potential power source for portable applications. However, the major drawbacks of DMFCs, including their high production costs, expensive catalysts, catalyst instability, thermal and water management and methanol crossover poisoning have motivated researchers and industry engineers worldwide to study DMFCs. Finding and preparing suitable catalysts to enhance the performance of DMFCs and tolerance to methanol are critical for the development of DMFCs.

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Most DMFC catalytic electrodes are made of either platinum (Pt) or platinum-based materials (Basri et al. [1]). Qiao et al. [2] developed a new plating process for producing the cathode catalyst of a micro-tubular direct methanol fuel cell. In this method, a thin porous layer of a Pt electro-catalyst was first bound to a tubular polymer electrolyte membrane via the chemical reduction of a Pt complex impregnated in the membrane. The high reactivity of Pt makes it a suitable anode electrocatalyst for DMFCs. However, pure Pt is readily poisoned by carbon monoxide (CO) which is formed by an indirect reaction during methanol oxidation. In order to avoid the formation of CO on Pt electrodes, platinum-alternative catalysts, binary or hybrid alloys of Pt, such as PtRu, PtSn (Sandoval-González et al. [3]), Pt-M (Baglio et al. [4]), PtMO (Martínez-Huerta et alo. [5]), PtPbMnO (Huang et al. [6]), and PtCo (Xu et al. [7], Vinayan et al. [8]) are generally employed as electrocatalytic materials on DMFC anodes. Baranton et al. [9] developed new electron-conductive polymers that were stable under an oxidizing environment and that possessed a high doping capacity for using platinum-alternative cathode catalysts in DMFCs. Guo et al. [10] investigated the structural and surface features and the electrocatalytic properties of bimetallic PtRu/Oxidized carbon nanofibers (OCNF) and PtRu/Reduced carbon nanofibers (RCNF). The OCNF-supported catalysts provided better performance than commercial catalysts when the current density was greater than 50 mA cm^{-2} despite the low methanol oxidation peak current density. In DMFCs, bimetallic PtRu is the most widely used catalytic material because of its high electrocatalytic activity towards methanol oxidation at the anode. Ru improved the electronic properties of Pt to prevent the adoption of CO by decreasing the oxidation overpotential of the anode (Ribeiro et al. [11]). However, slow reaction kinetics is a significant limitation that reduces the performance and power output of DMFCs. Baglio et al. [4] used a low-temperature preparation procedure to modify Pt catalysts with transition metals (Fe, Cu and Co). According to stripping analysis of the adsorbed methanolic residues, the Pt–Fe system exhibited better methanol tolerance and enhanced activity toward oxygen reduction. An improvement in the DMFC single cell performance was also observed in the presence of Pt–Fe catalysts. Wang et al. [12] used Ketjen Black EC 300Jas an additive in the cathode catalyst layer to improve the DMFC performance. The cathode catalyst layer with the Ketjen Black EC 300J additive showed greater single cell performance than the cathode catalyst layer without any additive, especially in the air-breathing mode. Choi et al. [13] developed a new type of Se/Ru catalyst called Se/Ru(aq) and studied the methanol tolerance and performance of the direct methanol fuel cell for the catalyst. They reported that the Se/Ru(aq) catalyst was highly tolerant to methanol crossing through the membrane (from the anode side) up to a feed concentration of 17 M. Compared to Pt cathodes, the performance of Se/Ru(aq) is significantly better under high methanol concentrations. Yao et al. [14] used a magnetron sputtering (MS) and metal-plasma ion implantation (MPII) technique to prepare a Pt–M/C catalyst. They reported that the membrane electrode assembly for Pt–Ni/C, Pt–Fe/C and Pt–Cr/C catalysts can enhance DMFC cell performance compared with traditional Pt/C and Pt–Ru/C.

With regard to studies of fuel channel of DMFCs, Hwang et al. [15] investigated the optimum flow channel design for DMFCs and explored the effect of the pressure drop across the inlet and outlet on the performance of the DMFCs with various flow channel designs. Yeh et al. [16] and Yarn et al. [17] investigated the performance of the DMFCs with different hydrophobic anode channel. They found that the performance of the DMFCs made of PDMS with high hydrophobic particles can be greatly enhanced and the hydrophobic property of the particles can be unaffected by different operation conditions. Chung et al. [18] investigated the effect of the anode channel width on the performance of the DMFCs and found that that the performance of DMFCs with smaller anode channels can be enhanced due to the uniform distribution of fuel on the anode collectors and the longer retention period of the fuel within the anode channels. However, when the width of the anode channel was less than $600\,\mu$ m, the hydro-resistance from the CO_2 bubbles produced within the anode channels seriously increased. Consequently, the output

of the DMFCs showed an obvious decrease. The performance of DMFC can be significantly reduced by methanol crossover. One method to reduce methanol crossover is to utilize a flowing electrolyte channel (FE–DMFC). Duivesteyn et al. [19] used hydrodynamic modeling to investigate the fluid dynamics in the porous domain of the flowing electrolyte channel and on the performance of a 1D isothermal FE-DMFC incorporating multiphase flow, in addition to modeling of the nonisothermal effects on the fluid dynamics of the FE-DMFC flowing electrolyte channel. Yarn et al. [20] added a 0.09 wt% of active carbon catalyst onto anode and cathode channels made of PDMS and indicated that under the same operating conditions, the performances of the DMFCs with an active carbon catalyst added onto their channels are always superior to those of DMFCs without a catalyst added. However, the proportional effect for different added catalysts on the performance of the DMFCs was not investigated in Yarn et al. [20].

This study aimed to investigate the output efficiency of DMFCs by coating different weight percentages of catalysts on the fuel channels to promote the fuel decomposition reaction within the channels and to further enhance the output of the DMFCs. At present, platinum is often used as the catalyst in MEA; however, Pt is still expensive. To reduce costs, this study employed active carbon and Se as alternative catalysts added to the fuel channels, as these catalysts have a similar effect and lower price than Pt. The effects of adding various proportions of the catalysts on the output efficiencies of DMFCs were investigated under different operating temperatures.

2. Experimental

2.1 Channel fabrication

In this study, the channel for the DMFCs using PDMS as the substrate was fabricated by injecting the PDMS material into a master mold on which reverse channel patterns were fabricated using lathe machining. The related injection-molding processes are shown in Fig. 1 and described below [16-18]:

(1) PDMS preparation: the silicone resin (Agent A) and the hardener (Agent B) are mixed in a 10:1 weight ratio, and then the mixture is uniformly mixed with different weight ratios of catalysts; the total weight is 35 g. For the weight proportions of 0.03%, 0.06%, 0.09%, 0.29% and 0.34%, the weight of added catalyst accounts for 0.01 g, 0.02 g, 0.03 g, 0.1 g and 0.12 g of the total weight, respectively.

(2) Vacuum treatment: because the mixing of Agents A and B in the previous step produces a large amount of bubbles, the mixed PDMS is placed into a vacuum chamber for vacuum treatment to completely remove the bubbles.

(3) Injection mold solidification and catalyst coating: the master mold is placed on a balanced stage, and then the vacuum-treated PDMS is injected into the master mold (8 cm x 8 cm). The channel area (3.5 cm x 3.5 cm) of the master mold is isolated using a custom-made square glass plate before injection, and then the PDMS containing the catalyst is injected into the channel area. The PDMS without catalyst fills up the exterior of the mold. Then, the glass plate is removed, and the mold is placed on a hot plate and heated at 70℃ for 30-40 min to complete the solidification of PDMS.

(4) Turning mold: the solidified PDMS is removed from the master mold. The fabricated channels with different concentrations of active carbon catalyst are shown in Fig. 2.
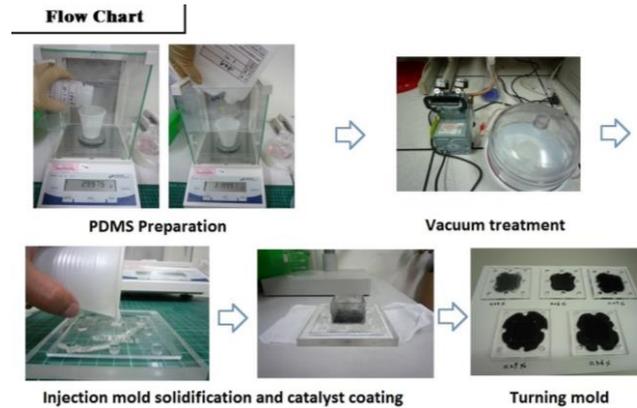
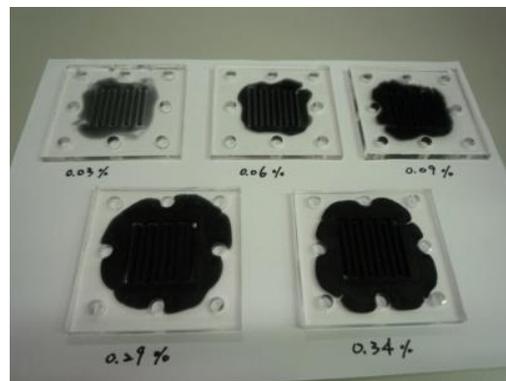*Fig. 1 Injection-molding processes of channel fabrication (Yarn et al. [20]).*

Fig. 2 Channels with different concentrations of active carbon catalyst (Yarn et al. [20]).

2.2 Transparent cell

Fig. 3 presents an exploded schematic of the transparent DMFC test fixture that was designed and fabricated for the visualization study presented in this paper. The MEA, which is detailed in the subsequent paragraph, was sandwiched between two bipolar plates with a gasket on either side of the MEA. This assembly, including the bipolar plates and MEA, was clamped between two enclosure plates using eight M8 screw joints (each having a torque of approximately 12 KGF-CM). The active area of the MEA used in this study is 3.5 cm×3.5 cm, which consisted of two single-sided ELAT electrodes from E-TEK and a Nafion[R]117 membrane. Both the anode and cathode electrodes used carbon cloth (E-TEK, Type A) as a backing support layer with a 30% PTFE water-proofing treatment. The catalyst loading on the anode side was 4.0 mg cm^{-2} with unsupported [Pt:Ru] Ox (1:1 a/o), where as the catalyst loading on the cathode side was 2.0 mg cm^{-2} with 40% Pt on Vulcan XC-72. Furthermore, 0.8 mg cm^{-2} Nafion[R] was applied to the surface of each electrode. The bipolar plates (shown in Fig. 3) were composed of 316 stainless steel with a thickness of 2.0 mm to avoid corrosion. As shown in Fig. 3, the rectangular bipolar plate consisted of two portions: the channel area and the extension area. The channel area acted as the distributor for supplying fuel and oxidant to the MEA. Serpentine fuel channel composed of nine parallel channels was used in this study. The cross section areas of the parallel channels are 2.0 mm×2.0 mm, between which the width of the ribs was 2 mm.
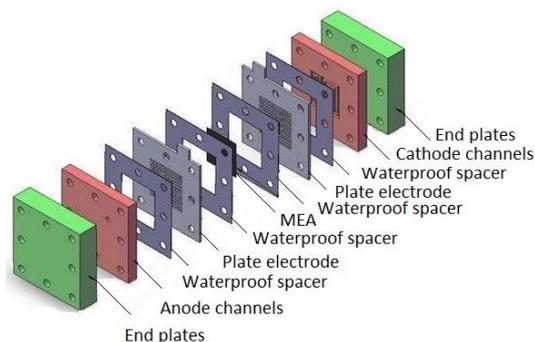
Fig. 3 Exploded view of the transparent DMFC test fixture (Yeh et al. [20]).

2.3 Experimental procedure

A schematic of the experimental setup is shown in Fig. 4. The methanol solution was driven by a squirm pump, which can precisely control the liquid flow rate from 3 to 15 ml/min with an error of 2%. Before entering the cell, the methanol solution was pre-heated to a desired temperature by placing the methanol solution tank in a temperature-controllable water bath. The mixture of CO_2 gas and un-reacted methanol solution was drained from the cell and cooled by passing through a cooling system. The gas (CO_2) produced at the anode was separated from the methanol solution tank and released to the atmosphere, while the un-reacted methanol solution was re-collected in a chemical liquid tank. Simultaneously, ambient air with approximately 21% oxygen as an oxidant was provided to the cathode side of the cell without humidification. The oxygen flow rate was controlled using an air mass flow regulator, which has an error of 5% of the full scale.
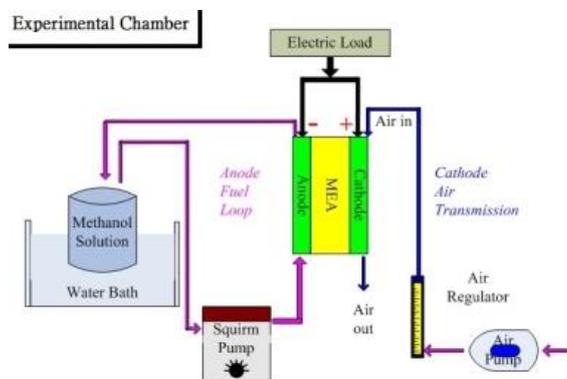

Fig. 4 Schematic diagram of experimental apparatus (Yeh et al. [20]).

As shown in Fig. 4, when the MEA is activated, the electronic DC loader is connected to the fuel cell by connecting the anode to the negative terminal and connecting the cathode to the positive terminal. The 0.6 V~0.2 V load is given in constant voltage mode, the time for each interval of 0.05 V is several minutes, and the voltage and current are recorded. The I-P curve and I-V curve are drawn, and the current density and power density distribution curves are established. All of the measurements of the investigated DMFCs were performed in an experimental chamber in which the temperature and humidity can be controlled.

3. Results and discussion

Yarn et al. [20] added a specific weight percentage of active carbon catalyst onto anode and cathode channels made of PDMS and indicated that under the same operating conditions, the

performances of the DMFCs with an active carbon catalyst added onto their channels are always superior to those of DMFCs without a catalyst added. In this study, different weight percentages of catalysts including Pt, active carbon and Se, were coated onto anode and cathode channels in order to investigate the adding weight percentages of the catalysts on the output of the DMFCs under various operating temperatures. In the experiments, 10% methanol solution was injected into the DMFCs with a flow rate of 10cc/min. Different weight percentages of catalysts were added onto the PDMS channels with a 2 cm width, and the performance of the DMFCs was tested under different operating temperatures (30℃, 40℃, 50℃, 60℃, and 70℃). Performance of DMFCs with different weight percentages of Pt catalyst added onto fuel channels.

3.1 Performances of DMFCs with different weight percentages of platinum catalyst added onto fuel channels

Table 1 presents the maximum power densities and corresponding increment percentages of the maximum power densities for the DMFCs with different Pt catalyst loadings under different operating temperatures. As shown in this table, the maximum power densities of the DMFCs increase with increasing operating temperature with the catalyst loading. At the same operating temperature, when a slight amount of Pt catalyst (0.03%) is added onto the fuel channels, the maximum power densities can be greatly enhanced, especially at the lower operating temperatures of 30℃ and 40℃. The enhancements in the output of the DMFCs result from the promotion of the fuel decomposition reaction by the catalyst added on the channels. Furthermore, Table 1 also shows that a critical value exists for the amount of Pt catalyst added: 0.06%. When the percentages added are greater than 0.06%, the enhancements in the maximum power densities of the DMFCs become unapparent because the fuel decomposition reactions promoted by the additive catalyst reach the tolerance of MEA, which may cause deterioration in the performance of the DMFCs. For the DMFCs, the maximum power density can reach the highest value of 21.50 mW・cm^{-2} by adding 0.09% Pt at the operating temperature of 70℃. Table 1 also presents the maximum power density increments of the DMFCs in comparison to those of DMFCs without catalyst added onto the channels at the same operating temperature. As shown, the maximum power density increment of 145.9% can be attained in the case with 0.09% catalyst added at an operating temperature of 30℃. Fig. 5 presents the power density distributions of DMFCs with different percentages of Pt catalyst added onto the fuel channels at an operating temperature of 70℃. As shown in this figure, the power densities of the DMFCs with Pt catalyst added onto the fuel channels under various current densities are always superior to those of the DMFC without catalyst added onto the channels. Furthermore, when the percentages of Pt added exceed 0.06%, the power density distributions become similar. This result demonstrates that a critical Pt catalyst loading exists for obtaining performance enhancement.

Table 1 Maximum power densities and corresponding increment percentage of DMFCs with different percentages of Pt catalyst added onto the channels at different temperatures.

Temperature	30°C		40°C		50°C		60°C		70°C	
	Maximum power density $(mW \cdot cm^{-2})$	Increment percentage (%)	Maximum power density $(mW \cdot cm^{-2})$	Increment percentage (%)	Maximum power density $(mW \cdot cm^{-2})$	Increment percentage (%)	Maximum power density $(mW \cdot cm^{-2})$	Increment percentage (%)	Maximum power density $(mW \cdot cm^{-2})$	Increment percentage (%)
0% Percentage	6.36	0	7.48	0	8.35	0	9.36	0	10.40	0
0.03%	13.36	110.1	15.21	103.3	16.51	97.7	18.27	95.2	19.66	89.0
0.06%	13.37	110.2	15.57	108.2	18.40	120.4	19.90	112.6	20.96	101.5
0.09%	15.64	145.9	16.89	125.8	18.81	125.3	20.13	115.1	21.50	106.7
0.11%	14.33	125.3	16.02	114.2	18.51	121.7	19.99	113.6	21.01	102.0

(1)　　Power density increment is defined as $(E_X - E_P)/E_P \times 100$ %, where E_X is the maximum power density of a DMFC with different percentages of catalyst added onto the channels and E_P is the maximum power density without the addition of catalyst to the channels at the same operating temperature.

(2)　　For the weight proportions of 0.03%, 0.06%, 0.09% and 0.11%, the amount of Pt catalyst added in the channel area accounts for 0.857mg cm^{-2}, 1.71mg cm^{-2}, 2.57mg cm^{-2} and 3.14mg cm^{-2}, respectively.
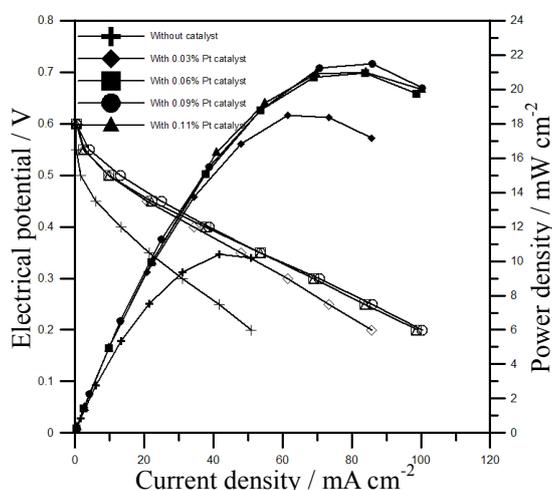

Fig. 5 Power densities of DMFCs with different percentages of Pt catalyst added onto the channels at an operating temperature of 70℃.

3.2 Performances of DMFCs with different weight percentages of active carbon catalyst added onto fuel channels

As shown in Table 2, when active carbon was added onto the fuel channels as a catalyst, the maximum power densities of the DMFCs also increase with increasing operating temperature; furthermore, the performances of the DMFCs with active carbon added are greatly improved compared to those without catalyst added onto the channels. In the cases of 0.29% and 0.34% weight percentages of active carbon catalyst added, the maximum power densities of the DMFCs reach 21.73 mW · cm^{-2} and 21.61 mW · cm^{-2} at 70℃, respectively. From Table 2, it can also be seen that when the percentage of catalyst added increases, the performances of the DMFCs also

gradually increase due to promotion of the fuel decomposition reaction by the catalyst added onto the channels. However, when the percentages added exceed 0.29%, the maximum power densities of the DMFCs slightly decrease because the fuel decomposition reactions promoted by the added catalyst exceed the tolerance of the MEA, which causes the crossover phenomenon and performance deterioration of the DMFCs. Thus, there exists a critical active carbon catalyst loading value of 0.29% for the active carbon catalyst. When the percentages of the catalyst added are less than this critical value, the output of the DMFCs can be greatly enhanced by increasing the percentage added onto the fuel channels. However, when the percentages added exceed the critical value, the efficiency enhancements become unapparent and even deteriorate. From Table 2, it can also be observed that with 0.29% catalyst, the maximum power density increment percentages of the DMFC are always superior to those of DMFCs with other catalyst loadings under the same operating temperature. The maximum power density increment of 119.4% can be attained with the addition of 0.29% catalyst at an operating temperature of 40℃.

Table 2 Maximum power densities and corresponding increment percentage of DMFCs with different percentages of active carbon catalyst added onto the channels at different temperatures.

Temperature Percentage	30℃		40℃		50℃		60℃		70℃	
	Maximum power density (mW・cm^{-2})	Increment percentage (%)	Maximum power density (mW・cm^{-2})	Increment percentage (%)	Maximum power density (mW・cm^{-2})	Increment percentage (%)	Maximum power density (mW・cm^{-2})	Increment percentage (%)	Maximum power density (mW・cm^{-2})	Increment percentage (%)
0%	6.36	0	7.48	0	8.35	0	9.36	0	10.40	0
0.03%	6.75	6.1	8.02	7.2	8.69	4.1	9.67	3.3	10.64	2.3
0.06%	11.53	18.3	13.46	79.9	14.32	71.5	15.08	61.1	15.99	53.8
0.17%	9.30	46.2	12.00	60.4	13.93	66.8	14.10	50.6	14.90	43.3
0.29%	12.39	94.8	16.41	119.4	18.19	117.8	19.98	113.5	21.73	108.9
0.34%	11.267	77.2	13.41	79.3	16.37	96.0	18.73	100.1	21.61	107.8

(1)   Power density increment is defined as $(E_X - E_P)/E_p \times 100$ % , where E_X is the maximum power density of a DMFC with different percentages of catalyst added onto the channels and E_P is the maximum power density without catalyst added onto the channels at the same operating temperature.

(2)   For the weight proportions of 0.03%, 0.06%, 0.17%, 0.29% and 0.35%, the amount of active carbon catalyst added in the channel area accounts for 0.857mg cm^{-2}, 1.71mg cm^{-2}, 4.86mg cm^{-2}, 8.29mg cm^{-2} and 10mg cm^{-2}, respectively.
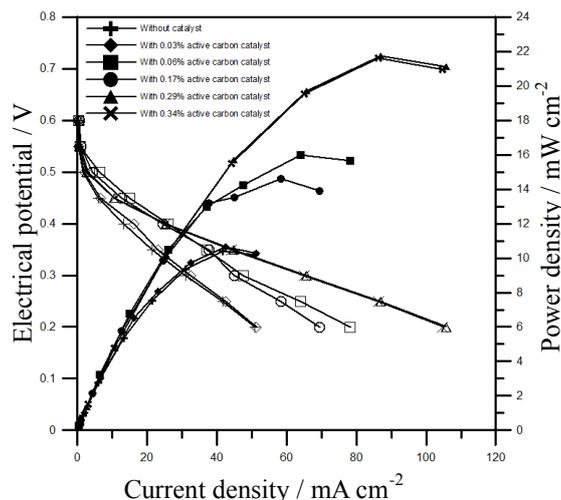
Fig. 6 Power densities of DMFCs with different percentages of active carbon catalyst added onto the channels at an operating temperature of 70 ℃.

Fig. 6 presents the power density distributions of DMFCs with different percentages of active carbon catalyst added onto the fuel channels at an operating temperature of 70℃. As shown, the power densities of the DMFCs with active carbon catalyst added onto the fuel channels under various current densities are always superior to those of the DMFC without catalyst added onto the channels. Furthermore, when the percentages of active carbon added exceed 0.29%, the power density distributions almost overlap. This result also demonstrates that there exists a critical catalyst loading value for obtaining performance enhancement.

3.3 Performances of DMFCs with different weight proportions of Se catalyst added onto fuel channels

Table 3 presents the maximum power densities and corresponding increment percentages of the maximum power densities for the DMFCs with different percentages of Se catalyst added under different operating temperatures. As shown in this Table, the maximum power densities of the DMFCs also increase with increasing operating temperature. At the same operating temperature, there still exists a critical catalyst loading value for the Se catalyst: 0.29%. When the percentages of Se catalyst added are less than 0.29%, the maximum power densities of the DMFCs also gradually increase as the amount of catalyst added increases. When the percentages added exceed 0.29%, the maximum power densities of the DMFCs severely decrease due to the crossover phenomenon of the DMFCs. For the DMFCs, the maximum power densities can reach the highest value of 19.16 mW $\cdot$ cm^{-2} by adding 0.29% Se at an operating temperature of 70℃. As shown in Table 3, at the catalyst loading of 0.29%, the maximum power density increment percentages of the DMFC are always superior to those of DMFCs with other catalyst loadings under the same operating temperature. The maximum power density increment of 182.2% can be attained in the case with 0.29% catalyst loading at an operating temperature of 30℃.

Table 3 Maximum power densities and corresponding increment percentage of DMFCs with different loadings of Se catalysts added onto the channels at different temperatures.

Temperature	30℃		40℃		50℃		60℃		70℃	
Percentage	Maximum power density (mW·cm⁻²)	Increment percentage (%)	Maximum power density (mW·cm⁻²)	Increment percentage (%)	Maximum power density (mW·cm⁻²)	Increment percentage (%)	Maximum power density (mW·cm⁻²)	Increment percentage (%)	Maximum power density (mW·cm⁻²)	Increment percentage (%)
0%	6.36	0	7.48	0	8.35	0	9.36	0	10.40	0
0.09%	11.03	73.4	13.18	76.2	14.29	71.1	14.95	59.7	15.35	47.6
0.14%	14.46	127.4	15.31	104.7	15.83	89.6	16.12	72.2	16.02	54.0
0.29%	17.95	182.2	18.19	143.2	18.77	124.8	18.92	102.1	19.16	84.2
0.43%	10.49	64.9	11.59	54.9	12.65	51.5	14.01	49.7	14.47	39.1
0.57%	8.91	40.1	10.87	45.3	11.54	38.2	12.82	37.0	13.60	30.7

(1) Power density increment is defined as $(E_X - E_P)/E_p \times 100$ %, where E_X is the maximum power density of a DMFC with different loadings of catalyst added onto the channels and E_P is the maximum power density without catalyst added onto the channels at the same operating temperature.

(2) For the weight proportions of 0.09%, 0.14%, 0.29%, 0.43% and 0.57%, the amount of Se catalyst added in the channel area accounts for 2.57mg cm⁻², 4mg cm⁻², 8.29mg cm⁻², 12.29mg cm⁻² and 16.29mg cm⁻², respectively.

Fig. 7 presents the power density distributions of DMFCs with different loadings of Se catalyst added onto the fuel channels at an operating temperature of 70℃. It can be observed that the power densities of the DMFCs with the Se catalyst added onto the fuel channels under various current densities are always superior to those of the DMFC without catalyst added onto the channels. Furthermore, it can be observed that with a catalyst loading of 0.29%, the output of the DMFC possesses superior performance in comparison to those with other catalyst loadings. This result also demonstrates that there exists a critical Se catalyst loading value for obtaining performance enhancement. Fig. 8 presents a comparison of the power densities of DMFCs with corresponding critical catalyst loading values at an operating temperature of 70 ℃. The performance of the DMFCs with appropriate catalyst loadings can be effectively enhanced. The DMFC with the Pt catalyst possesses the best performance among the DMFCs, but the differences between the DMFCs with Pt and active carbon catalysts are not large. Due to the high price of the platinum catalyst, it is recommended that the alternative catalyst of active carbon be added onto the fuel channels for further performance enhancement.
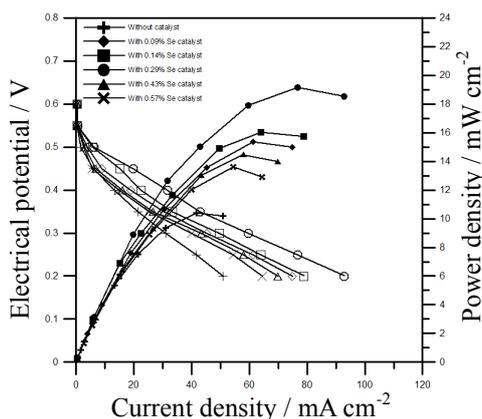
Fig. 7 Power densities of DMFCs with different loadings of Se catalyst added onto the channels at an operating temperature of 70℃.
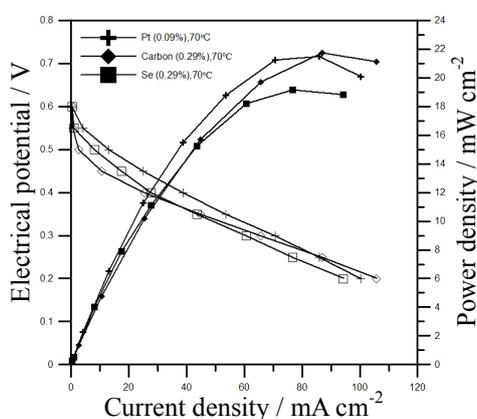

Fig. 8 Comparison of power densities of DMFCs with corresponding threshold percentage values of catalysts added onto the fuel channels at an operating temperature of 70℃.

4. Conclusions

This study investigated the enhancement effects of adding different weight percentages of catalysts onto the fuel channels on the output performance of DMFCs under different operating temperatures. Three different types of catalysts, Pt, active carbon and Se, were added onto the fuel channels, which were composed of PDMS. The results indicated that the performances of the DMFCs can be greatly enhanced by adding appropriate percentages of catalysts onto the channels due to promotion of the fuel decomposition reaction within the channels. However, critical values for the percentage of catalyst added exist for every DMFC investigated in this study. When the percentages added are greater than the corresponding critical value, the maximum power densities of the DMFCs may decrease due to the limited tolerance of MEA. In this study, the highest maximum power density of 21.73 mW · cm^{-2} was obtained for the DMFC with 0.29% active carbon catalyst at an operating temperature of 70℃. In comparison to the maximum power densities of the PDMS channel without catalyst at various operating temperatures, the highest maximum power density increment of 182.3% was attained for the DMFC with 0.29% Se catalyst added onto the channels at an operating temperature of 30℃. Furthermore, the results indicated that for the DMFCs with the same percentages of added catalyst, higher maximum power density increments can usually be obtained under lower operating temperatures because lower temperatures can retard the crossover effect in the DMFCs. The experimental results suggested that adding an appropriate percentage of catalyst to the channel is beneficial for increasing the efficiency of DMFCs. At present, the platinum catalyst is still expensive. To reduce the cost, a

catalyst with the same effect but a lower price can be used as an alternative to be added onto fuel channels.

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