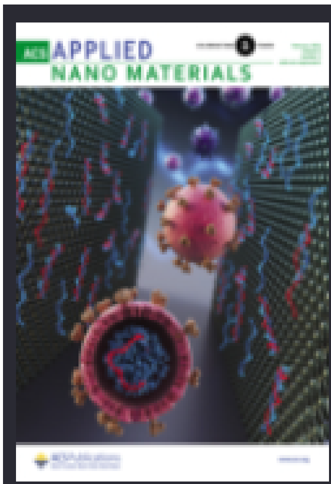

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A Triple Bioinspired Surface Based on Perfluorodecyl Trimethoxysilane-Coated ZnO Nanosheets for Self-Driven Water Transport in a Flow Channel

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Abstract

Water management is important for the bipolar plates of proton-exchange membrane fuel cells (PEMFCs), and active drainage is a desirable feature for the design of bipolar plate channels. Herein, inspired by natural micro-nanostructures, a triple bioinspired surface has been fabricated, which combines the advantages of both superhydrophobic and superhydrophilic surfaces. The superhydrophobic surface (FZnO@CA-GS) is prepared by PFTS (perfluorodecyl trimethoxysilance) coating on ZnO nanosheet-decorated arrays of microscale cylinders manufac-tured by photolithography, and second-round photolithography is used to convert the superhydrophobic surface into a surface with wedged superhydrophilic patterns (WSPs). Then, the water transport performance has been investigated for the WSP, where the square of the initial velocity of the droplet is found to be proportional to the wedge angle from both the theoretical calculation and experimental data. Subsequently, an index of the R value representing the flow state of droplets has been introduced to determine the optimal values for the geometrical parameters of triple-bioinspired surface (TBS) in flow channels. Such a triple bioinspired strategy affords a promising approach to fabricate bipolar plate channels with the function of self-driven water transport for PEMFC. The use of the R value in optimization may also offer insights into the design of other micro-nanostructures.

Keywords

Author Keywords: bioinspired surface; ZnO nanosheets; water transport; flow channel; proton-exchange membrane fuel cells (PEMFCs)

Keywords Plus: MEMBRANE FUEL-CELL; BIPOLAR PLATES; WETTABILITY; CACTUS; PERFORMANCE; FABRICATION; FIBERS; WOOD

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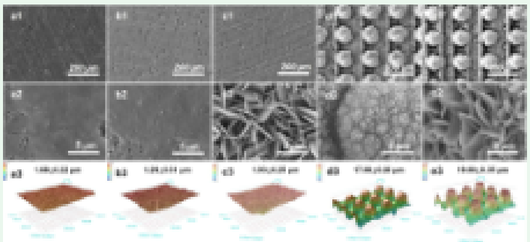

ABSTRACT: Water management is important for the bipolar plates of proton-exchange membrane fuel cells (PEMFCs), and active drainage is a desirable feature for the design of bipolar plate channels. Herein, inspired by natural micro-nanostructures, a triple bioinspired surface has been fabricated, which combines the advantages of both superhydrophobic and superhydrophilic surfaces. The superhydrophobic surface (FZnO@CA-GS) is prepared by PFTS (perfluorodecyl trimethoxysilance) coating on ZnO nanosheet-decorated arrays of microscale cylinders manufactured by photolithography, and second-round photolithography is used to convert the superhydrophobic surface into a surface with wedged superhydrophilic patterns (WSPs). Then, the water transport performance has been investigated for the WSP, where the square of the initial velocity of the droplet is found to be proportional to the wedge angle from both the theoretical calculation and experimental data. Subsequently, an index of the *R* value representing the flow state of droplets has been introduced to determine the optimal values for the geometrical parameters of triple-bioinspired surface (TBS) in flow channels. Such a triple bioinspired strategy affords a promising approach to fabricate bipolar plate channels with the function of self-driven water transport for PEMFC. The use of the *R* value in optimization may also offer insights into the design of other micro-nanostructures.

KEYWORDS: *bioinspired surface, ZnO nanosheets, water transport, flow channel, proton-exchange membrane fuel cells (PEMFCs)*

1. INTRODUCTION

Proton-exchange membrane fuel cells (PEMFCs) are considered as an important technology to mitigate energy shortage and environmental pollution, owing to its high energy conversion efficiency and environmental friendliness.[1] However, the commercial application of PEMFCs requires a stable operation at a desirable performance, which is affected by various factors, such as electrocatalyst activity, mass transfer, water transport, and electrode conductivity. Among these factors, water management is an important issue to improve the performance of PEMFCs.[2] The main reasons are as follows: on the one hand, a certain amount of water must be maintained inside the PEMFC to ensure that the proton-exchange membrane has favorable proton conductivity.[3,4] On the other hand, excessive water should be drained out of the PEMFC to prevent water flooding, which could impede gas transfer to the catalytic layer and impair normal electrochemical reaction. Hence, various investigations have been conducted to change the wettability of the channel in the bipolar plates of the PEMFC to achieve optimal water removal.[5]

Interestingly, the published reports on the channel surface have shown that either hydrophilic or hydrophobic modifications can improve water management for PEMFCs, but their intrinsic mechanisms are quite opposite.[6−9] It has been demonstrated that the hydrophobic surface is beneficial to water removal in the channel of the bipolar plate because of lower adhesion and greater gas shearing. Wang et al.[10] have reported two kinds of surfaces on graphite channels, which are coated with superhydrophobic silica/polydimethylsiloxane composites or superhydrophilic silica. The results show that the superhydrophobic surface has lower adhesion to water, leading to easier water removal. Therefore, this surface can achieve better PEMFC performance than the counterpart of the hydrophilic surface under the same airflow. Taniguchi and Yasuda[11] have prepared a superhydrophobic thin film of polyhexafluoropropylene on the channel surface of the stainless-steel bipolar plate via plasma polymerization and sandblasting, which increases the output power of the PEMFC compared to that of the PEMFC with the original stainless

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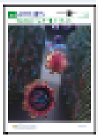

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Outline

Highlights

Abstract

Graphical abstract

Keywords

1. Introduction

2. Experimental section

3. Results and discussion

4. Conclusions

Declaration of Competing Interest

Acknowledgements

Appendix A. Supplementary data

Data availability

References

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Nature-inspired hybrid wettability surface to enhance water management on bipolar plates of PEMFC

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Proton exchange membrane fuel cell (PEMFC) requires both sufficient water in proton exchange membrane (PEM) and fast water drainage in flow channel to achieve a desirable performance, which creates a dilemma for water management. Herein, we have fabricated a nature-inspired bionic multifunctional surface (BMS) consisting of superhydrophobic coating and superhydrophilic groove. The characterizations of water contact angle, morphology and chemical composition have verified the successful preparation of hybrid wettability surface. The effects of groove width on droplet capture, storage and drainage have been investigated, which yields an optimal width of 600 mu m. More importantly, BMS has been fabricated inside the flow channel of graphite bipolar plate (BMS@BP). The peak power density of BMS@BP cell is 26.3% higher than that of the cell without BMS. Under a drought-inclined condition of low current and humidity, BMS@BP mitigates the increase of internal resistance caused by PEM dry-out, whereas under a condition prone to flooding (high current and humidity), BMS@BP can reduce the voltage fluctuation and pressure drop variation incurred by flooding. Hence, BMS has demonstrated a capacity to balance the opposite needs of moisturizing PEM and draining channel water. Our work may afford an innovative hybrid-wettability-based approach to enhance water management for PEMFC.

Keywords

Author Keywords: Nature -inspired surface; Hybrid wettability; Water management; Bipolar plates; Proton exchange membrane fuel cell (PEMFC)

Keywords Plus: FUEL-CELL; 2-PHASE FLOW; MEMBRANE; TRANSPORT; TEMPERATURE; PERFORMANCE; FABRICATION; COATINGS; LAYER; FIELD

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ABSTRACT

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1. Introduction

Water management is essential for the long-term, reliable operation of proton exchange membrane fuel cell (PEMFC) [1–4]. Excessive water easily induces flooding in flow channels, hindering mass transfer on bipolar plates (BP) [5,6], whereas insufficient water content may reduce the proton transport of proton exchange membrane (PEM) and increase internal resistance [7,8]. Hence, researchers have adopted various strategies to improve the water management of PEMFC, which include adjusting cell operating conditions [9,10], developing new cell component materials [11,12] and designing novel flow fields [13–18]. Although these methods have greatly enhanced water management and cell performance, some challenges still remain for practical applications, such as high manufacturing cost and parasitic losses.

Adjusting surface wettability is an effective and thus frequently used approach for water management [19,20]. Both hydrophilic and hydrophobic surfaces have been demonstrated with improved water management. Nishida *et al.* have compared the cell performance for flow channels of different wettability and found that hydrophilic flow channels can alleviate flooding and reduce pressure drop [21]. Conversely, Kahveci *et al.* have shown that hydrophobic flow channels can achieve better water drainage and reduce flooding in PEMFC [22]. These seemingly contradictory results implicate that hydrophilic and hydrophobic surfaces may adopt distinct mechanisms to enhance water management and are suitable for different working conditions. When PEMFC works at a low current, only a small amount of water is produced at slow electrochemical reaction rate. Therefore, the PEM tends to dry out to increase resistance. Hydrophilic channels with high surface energy can capture liquid water entrained in humidified air and deliver uniform water distribution, thus relieving the drought of PEM [23]. In contrast, excessive liquid water that cannot be discharged in time at high current density may accumulate in the gas diffusion layer, obstruct the path of reactants and impair the performance of PEMFC. In this scenario, hydrophobic channels with low surface energy can facilitate rapid drainage and restore mass transfer efficiency [24]. Taking these two cases together, a single adjustment of the wettability in flow channel

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