

Biphilic Porous Transport Layer Enabled High Efficiency and High-current Density Proton Exchanger Membrane Electrolyzer

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Primary CNF Tools Used: ABM Contact Aligner, Heidelberg MLA 150 Maskless Aligner

Abstract:

Green hydrogen is considered one of the most promising energy carriers for achieving carbon neutrality, offering a scalable solution for long-duration, high-energy-density energy storage. Among various production technologies, proton exchange membrane water electrolysis (PEMWE) stands out due to its high energy efficiency, compatibility with intermittent renewable energy sources, and ability to generate high-purity hydrogen.

However, at high current densities, PEMWE systems suffer from significant mass transport losses, particularly due to limitations in water and gas transport within the porous transport layer (PTL). [1,2]

This research proposes a novel design for the PTL aimed at enabling ultrahigh current density operation ($>5 \text{ A/cm}^2$) with enhanced energy efficiency. The design introduces a biphilic pattern (figure 1), comprising spatially alternating hydrophilic and hydrophobic regions, into the PTL to facilitate mass transport. Hydrophilic regions promote continuous water delivery to the catalyst layer, while hydrophobic regions facilitate oxygen gas removal. The biphilic pattern is fabricated using photolithographic techniques, followed by coating of hydrophobic particles. After development and photoresist removal, the resulting PTL exhibits distinct wetting regions. Preliminary analysis suggests that this design may double the energy efficiency under ultrahigh current density conditions.

Summary of the Research:

The proposed biphilic pattern is designed to enhance mass transport on the anode side of the PEM electrolyzer by facilitating the removal of oxygen bubbles through dry hydrophobic channels. These hydrophobic regions leverage capillary pressure in the PTL's microstructure

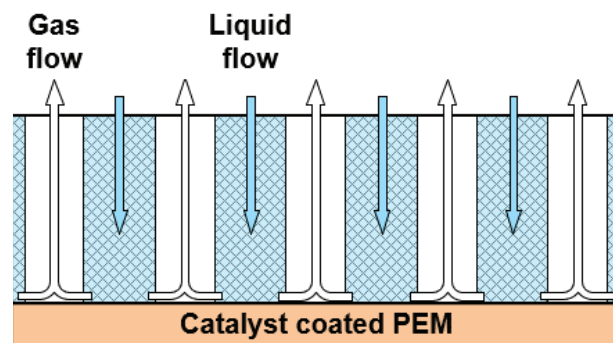


Figure 1: Figure 1: Schematic illustration of the biphilic porous transport layer (PTL) design.

to drive oxygen out of the cell, while hydrophilic regions ensure continuous water supply to the catalyst layer. This spatial separation of gas and liquid transport pathways minimizes bubble accumulation on the catalyst surface, therefore reducing overpotentials and enhancing overall electrochemical performance [3].

To demonstrate the feasibility of the patterning approach, initial experiments were conducted on silicon wafers due to their flat geometry and ease of processing. A thin layer of P20 MICROPOSIT™ PRIMER was applied, followed by spin-coating of SHIPLEY MICROPOSIT™ S1827 photoresist. After soft baking, the samples were exposed to UV light using an ABM contact aligner and developed to define the desired pattern. The developed samples were then uniformly coated with hydrophobic particles. Finally, the photoresist was removed using MICROPOSIT™ REMOVER, leaving hydrophobic particles only on the exposed regions, thereby forming the intended biphilic pattern. As shown in Figure 2, water droplets deposited on each region exhibit distinctly different contact angles, confirming successful formation of a biphilic surface.

Subsequently, the fabrication was extended to titanium PTL substrates. The samples were diced to the desired size using a DISCO dicing saw. A simplified design—



Figure 2: Water droplets on silicon wafer demonstrating biphilic pattern formation.



Figure 3: Water droplets on titanium porous transport layer with a simplified biphilic pattern.

comprising one large hydrophilic region adjacent to a large hydrophobic region—was fabricated to examine wetting contrast by following the same procedure as the silicon wafers. Figure 3 displays the resulting patterned PTL.

However, experimental observations revealed incomplete removal of hydrophobic particles from the photoresist-covered areas, resulting in partial hydrophobicity in regions intended to be hydrophilic. The final photomask design, generated using the Heidelberg Mask Writer DWL2000, was successfully used to produce high-resolution micro-patterns on titanium substrates, though the final coating step is pending resolution of the contamination issue.

Conclusions and Future Plans:

Microscale patterning was successfully achieved on both silicon and porous titanium substrates. However, the incomplete removal of hydrophobic particles remains a key challenge, affecting the fidelity of the biphilic pattern. Future work will focus on enhancing the contrast between hydrophilic and hydrophobic regions through optimized cleaning procedures, including alkaline treatment and plasma exposure. Additionally, further refinement of the photolithography parameters will be pursued to improve resist coating uniformity on the porous PTL surface and ensure pattern integrity. These steps are critical to fully realizing the potential of the proposed PTL design for high-efficiency PEMWE operation.

References:

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