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Biomimetic integrated gas diffusion layer inspired by alveoli for enhanced air-breathing fuel cell performance and stability

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Content

SI-1 Chemicals, materials, and Experimental details

1. Chemicals and materials

Nafion emulsion (5 wt%) and proton exchange membrane (Nafion XL, Dupont, USA). H_2O_2 (30 wt %), H_2SO_4 (98 wt%), ethanol and isopropanol (Sinopharm Chemical Reagent Co., Ltd. China.). Pt supported on XC-72R active carbon (JM 70 wt% Pt). Conductive adhesive (DAD-87, Shanghai Research Institute of Synthenic Resins Co., Ltd.). Silver foil (10 μm thickness, Quanzhou Jiadai New Materials Co., Ltd.). Carbon paper (Toray, TGP-060) with micro porous layer (2 mg cm^{-2} Vulacn-x-72R, 20% PTFE).

2. Experimental details

2.1 Preparation of biomimetic integrated gas diffusion layer (GDL).

First, the dry and clean silver foil is placed on the workbench of the ultraviolet laser marking machine to ensure the flatness of the silver foil as much as possible. The laser marking software is used to set the pore diameter, spacing, and range. Adjust the laser current and marking times to ensure that the laser etching depth can penetrate through the silver foil. The size of the silver foil is 8.5 cm × 2.5 cm, and the pore size ranges from 0.2 to 1.1 mm, with pore spacing of 0.2 to 1.9 mm, and a total pore area of 8 cm × 2.5 cm. The additional 0.5 cm is reserved for connecting the external circuit. For a 10 μm thick silver foil, the marking current is set to 9 A, and the marking number is set to 40 times.

Second, after laser marking, the silver foil is cleaned with ethanol and then left to dry naturally, resulting in a perforated silver foil.

Third, DAD-87 conductive adhesive was used to bond the perforated silver foil and the carbon paper biomimetic GDL. The conductive adhesive is evenly coated on one side of the perforated silver foil. Then, the perforated silver foil is carefully adhered to the carbon paper, and the assembly is dried in the oven at 100 °C for 1 hour, followed by 200 °C for 2 hours.

2.2 Preparation of MEA

The MEA's active area is 2.5 cm × 8 cm, *i.e*, 20 cm^2, and it was prepared and utilized in this study as follows: The catalyst ink consisted of 70% Pt/C and Nafion dissolved in a mixture of water and isopropyl alcohol (1:1 volume ratio). The ink was prepared using ultrasonography at low temperatures (below 25℃). The Nafion mass fraction in the ink was 20%, and the mass ratio of Pt/C to the solvent was 1:20. The biomimetic integrated GDL was placed on a 60℃ heating table, with the carbon paper side facing up. Next, the catalyst was evenly coated on the carbon paper using a brush. Subsequently, it was placed in the oven and dried at 105 °C for 1 hour. Following the drying process, the proton exchange membrane was positioned in the middle of the biomimetic integrated GDL. A pressure of 45 kgf cm^{-2} was applied at 130 °C for 2 minutes.

2.3 **Assembly of the fuel cell stack**

Firstly, the fuel cell with an active area of 2.5 cm×8 cm was fabricated by biomimetic integrated electrode (D=0.7 mm, d=1.3 mm). Next, the fuel cell stack is assembled using two fuel cells sealed face-to-face as the basic unit. Each assembled basic unit is fixed onto a hollow plastic support plate. The plastic support plate is then inserted into vertical plastic columns, providing structural stability to the stack. All fuel cell units in the stack are connected in series, with the cathodes and anodes connected using silver foil.

2.4 **Fuel cell test**

All the fuel cells in the work are air-breathing fuel cells. For air-breathing fuel cell, the cathode side is exposed directly in the air, and the air is supplied passively. For the fuel cell with the effective area of 2.5 cm×8 cm, the flow of hydrogen is 50 mL min^{-1}. The test environment is 25 °C and atmospheric pressure. For fuel cell stack, the flow of hydrogen is 40 mL min^{-1} for each fuel cell.

3. Characterizations

The structure of the array pore silver foil was characterized using a digital camera. The morphology of biomimetic integrated GDL and biomimetic integrated electrode was obtained by scanning electron microscope (Quanta 250 FEG, S-4800). The square resistance of integrated electrode was measured with four probes resistances meters (ST2258C). The square resistance of the integrated electrode is the Gaussian fitting value after 10 measurements. The performance of the fuel cell (2.5 cm×8 cm) and the fuel cell stack were obtained by discharging equipment (BST-10V20A-8CH, BettaTeQ). The polarization curve was gained by constant current discharge.

SI-2 Effect of hydrogen flow rate on cell performance.

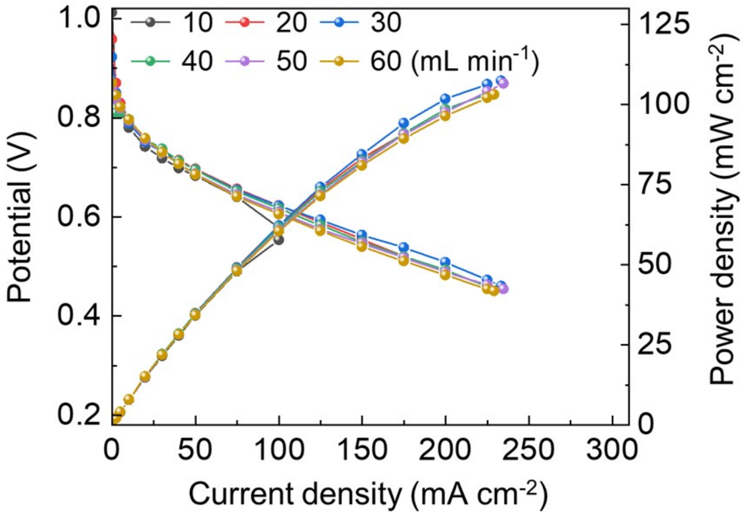

Figure S 1. Effect of hydrogen flow rate on fuel cell performance.

SI-3 The optical photo of biomimetic integrated electrode.

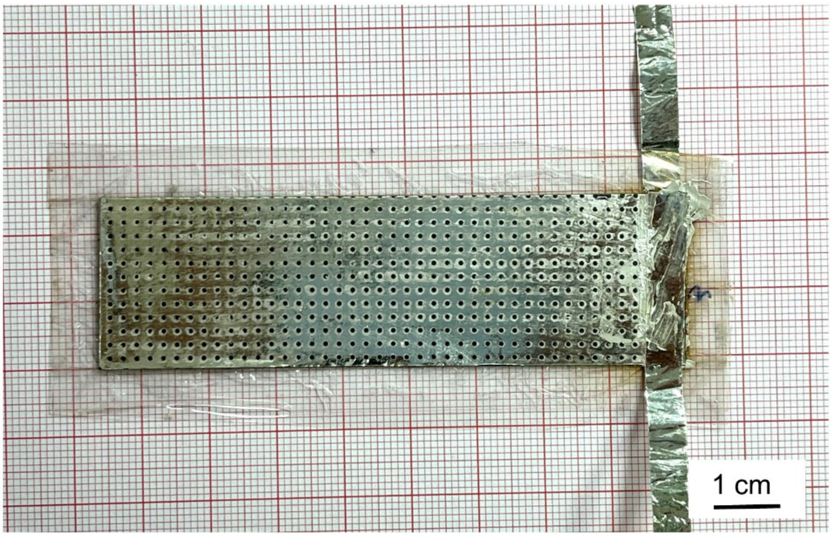

Figure S 2. The optical photo of biomimetic integrated electrode. The size of the biomimetic integrated electrode is 2.5 cm×8 cm.

SI-4 Original SEM images during the preparation process of biomimetic integrated GDL.

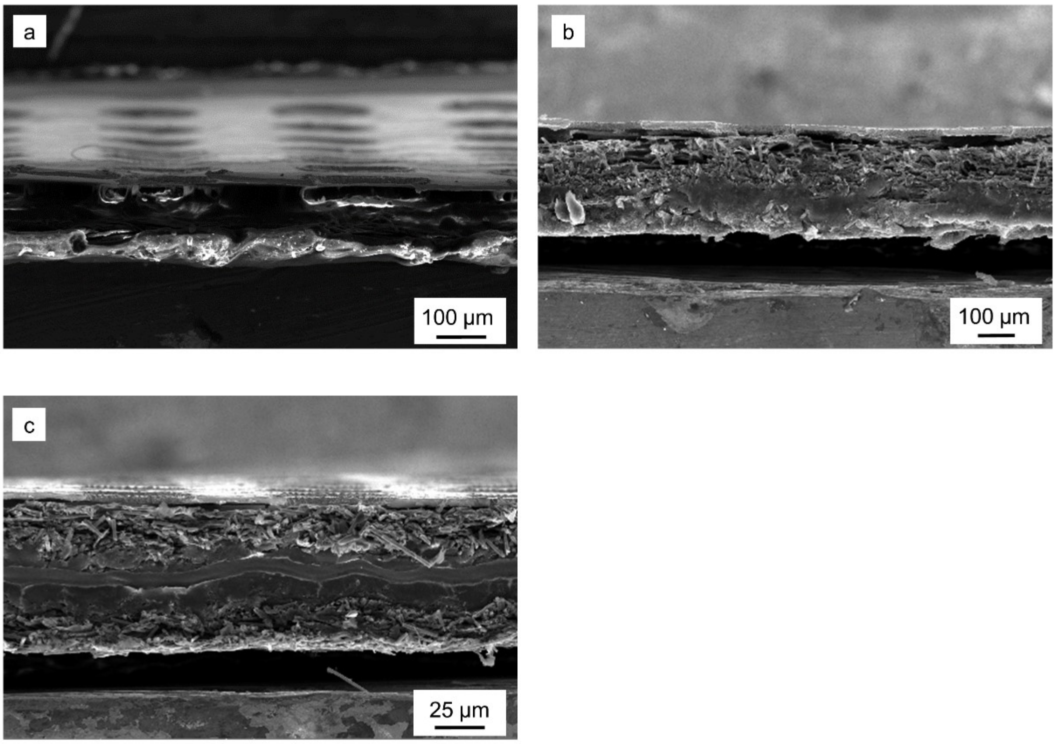

Figure S 3. Original SEM images during the preparation process of biomimetic integrated GDL. (a) Cross section SEM image of perforated silver foil. (b) Cross section SEM image of biomimetic integrated GDL. (c) Cross section SEM image of MEA.

SI-5 The effect of wind speed on polarization curves of different biomimetic alveoli numbers.

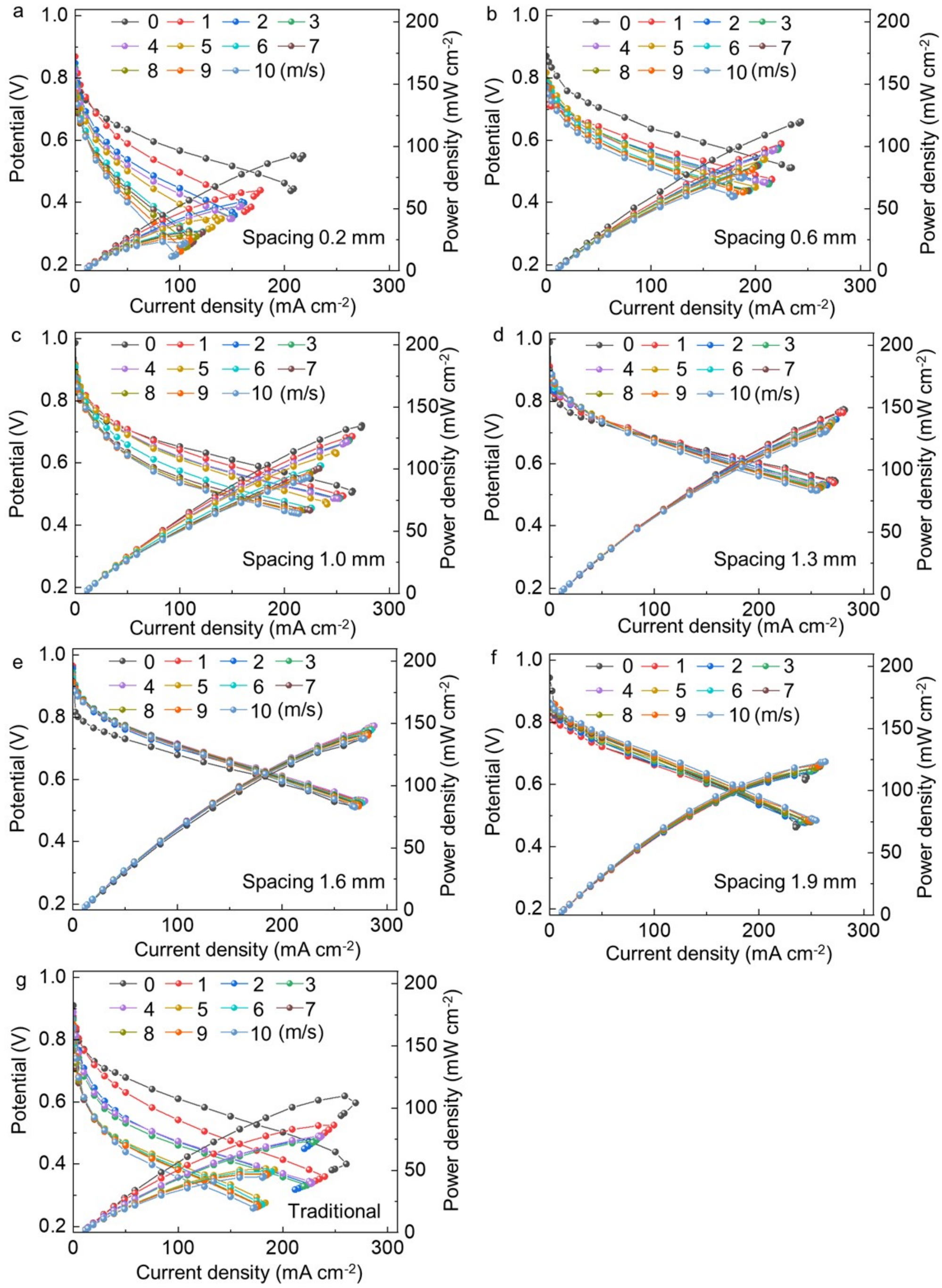

Figure S 4. The effect of wind speed on polarization curves of different biomimetic alveoli numbers. (a) Opening spacing is 0.2 mm. (b) Opening spacing is 0.6 mm. (c) Opening spacing is 1.0 mm. (d) Opening spacing is 1.3 mm. (e) Opening spacing is 1.6 mm. (f) Opening spacing is 1.9 mm. (g) Traditional AB-PEMFC.

SI-6 Testing device for the adaptability of biomimetic integrated GDL at different temperatures.

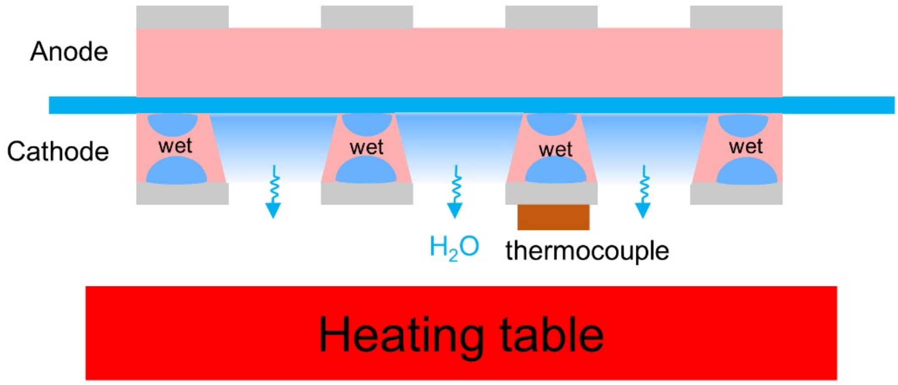

Figure S 5. Scheme of the high temperature testing device for the AB-PEMFC.

SI-7 The effect of temperature on polarization curves of different biomimetic alveoli numbers.

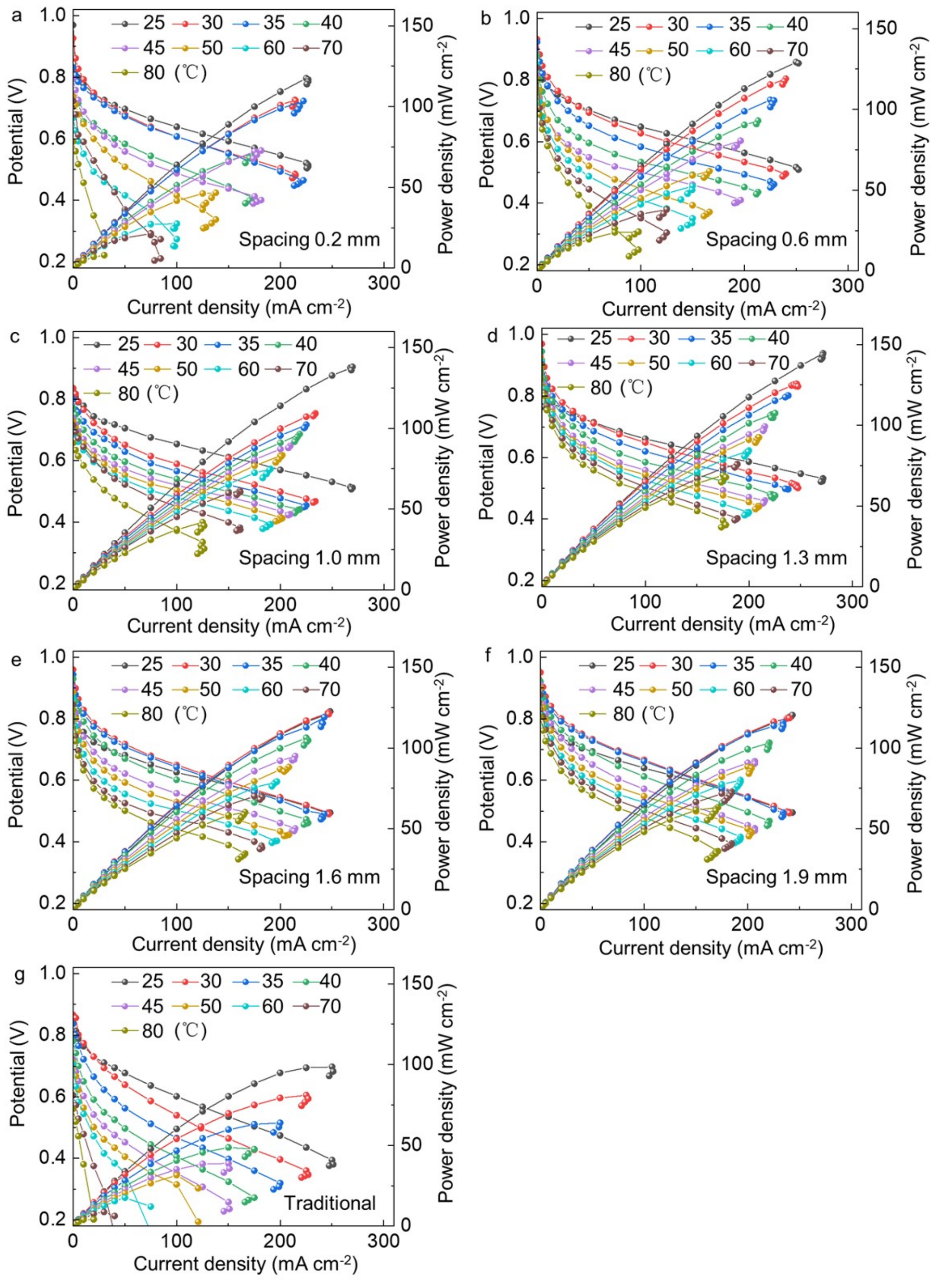

Figure S 6. The effect of temperature on polarization curves of different biomimetic alveoli numbers. (a) Opening spacing is 0.2 mm. (b) Opening spacing is 0.6 mm. (c) Opening spacing is 1.0 mm. (d) Opening spacing is 1.3 mm. (e) Opening spacing is 1.6 mm. (f) Opening spacing is 1.9 mm. (g) Traditional AB-PEMFC.

SI-8 Polarization curve of single cell and single sealed series in fuel cell stack.

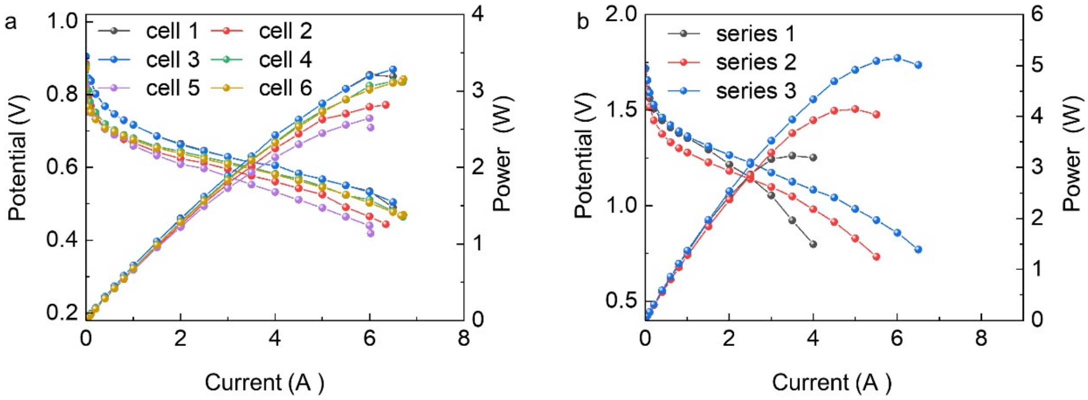

Figure S 7. Polarization curve of single cell and single sealed series in fuel cell stack.

SI-9 Temperature changes during long-time constant current discharge of a stack.

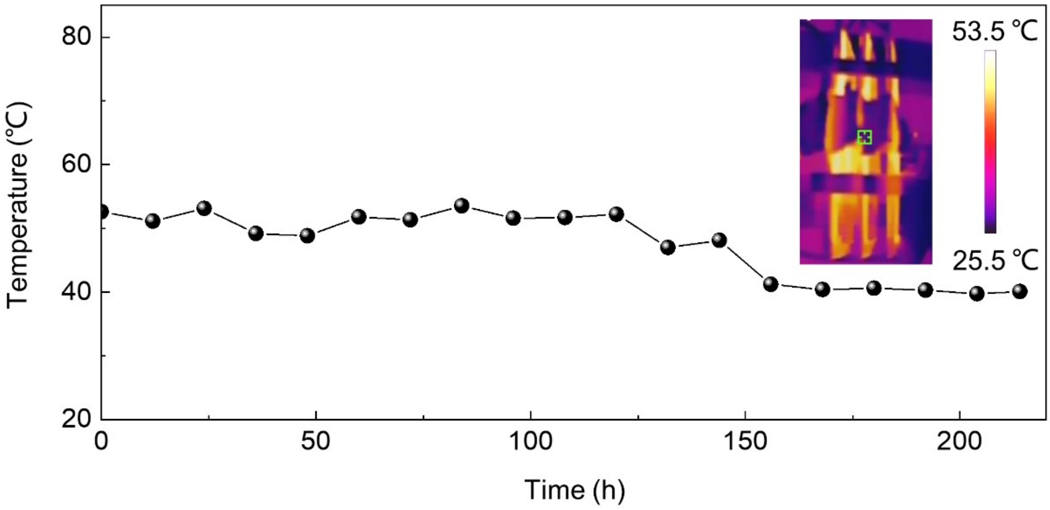

Figure S 8. Temperature changes during long-time constant current discharge (3.5 A for 210 h) of a stack.

SI-10 The biomimetic air-breathing PEMFC testing device.

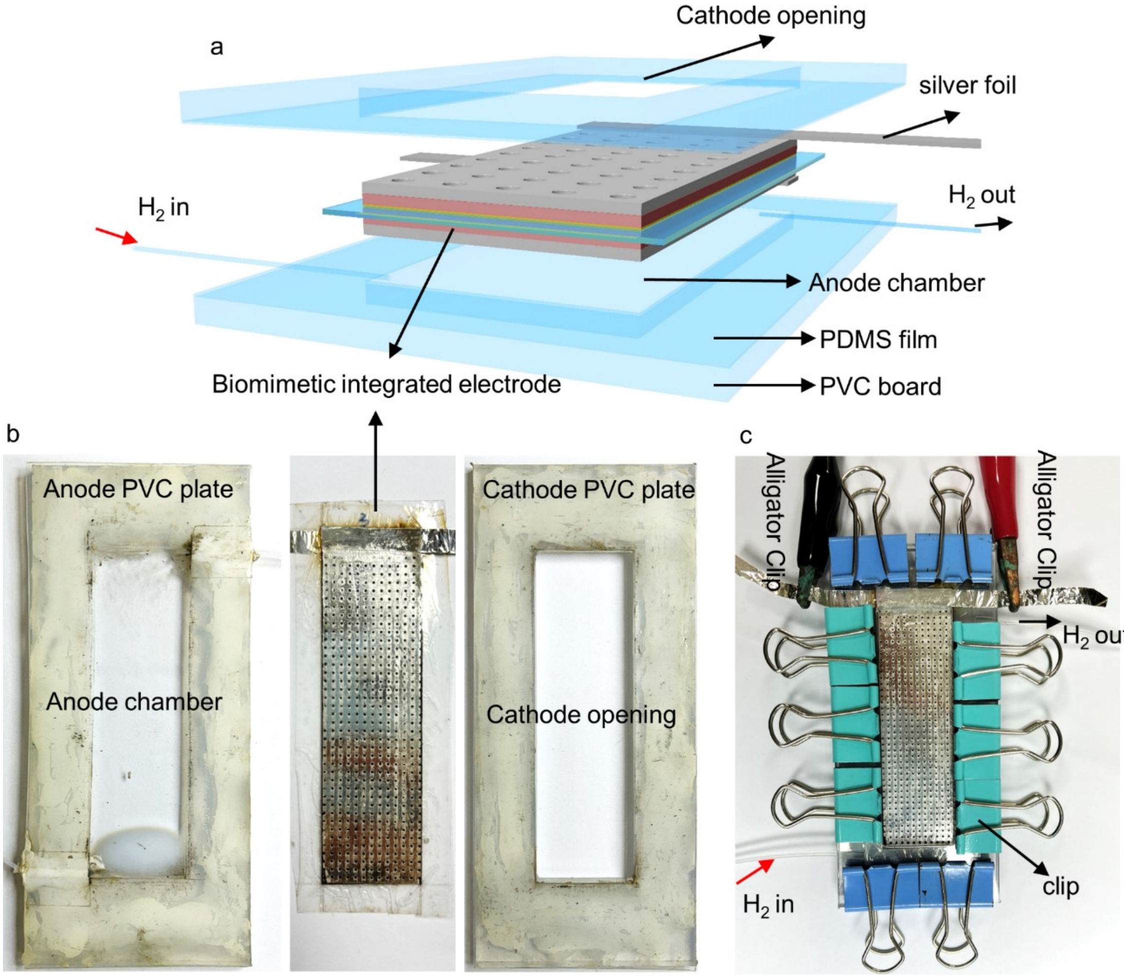

Figure S 9. The biomimetic air-breathing PEMFC testing device. (a)The scheme of biomimetic air-breathing PEMFC testing device. (b) The photograph of every unit of the biomimetic air-breathing PEMFC testing device. (c) The photograph of biomimetic air-breathing PEMFC testing device

SI-11 Fuel cell stack size and mass parameters.

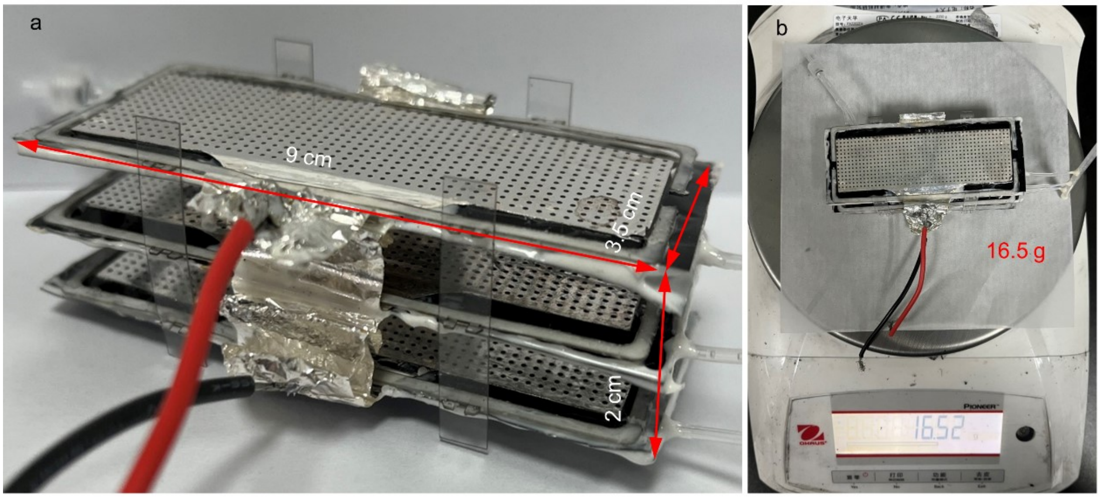

Figure S 10. Fuel cell stack size and mass parameters. (a) Fuel cell stack size parameters. (b) Fuel cell stack weight test.