The 29th The International Energy and Environment Conference

Design, Fabrication, and Performance Evaluation of a Portable Planar Proton Exchange Membrane Fuel Cell Employing Titanium Fiber Felt Current Collectors

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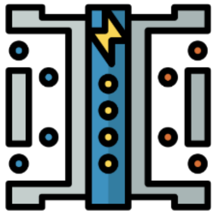
Outline



- Introduction
- Single-Cell Design and Optimization
- 2-Cell FC
- 4-Cell FC
- Portable Power Generation System
- Conclusions and Future Work

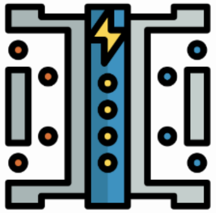
Introduction

International Agreements

Since the Industrial Revolution in the 17th century, greenhouse gas emissions have increased year by year. International organizations such as the WMO, UNEP, and IPCC have been established and have signed numerous climate agreements to achieve carbon reduction goals.

Hydrogen Energy

Hydrogen is a zero-carbon energy source with high energy density, capable of efficiently storing and transporting energy.



PEMFC

Proton exchange membrane fuel cells convert chemical energy into electrical energy through redox reactions, featuring high energy conversion efficiency.

Practical Application

They are commonly assembled into fuel cell stacks and applied to various types of vehicles (such as hydrogen-powered cars, drones, etc.).

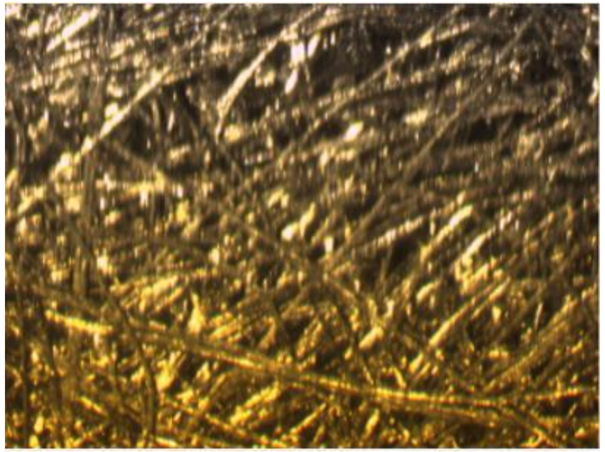
Research motivation

- Titanium and Titanium Felt -

Titanium and Titanium Felt

- Low density
- High mechanical strength
- Excellent corrosion resistance

- Three-dimensional porous structure
- Gas Transport
- Water Management



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Research motivation

- Fuel cell configuration-

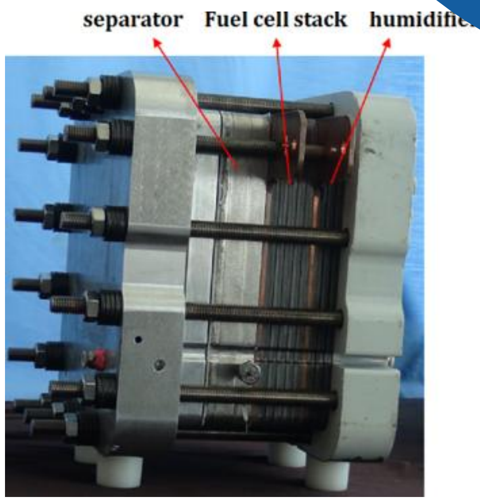
Fuel cell stack configuration

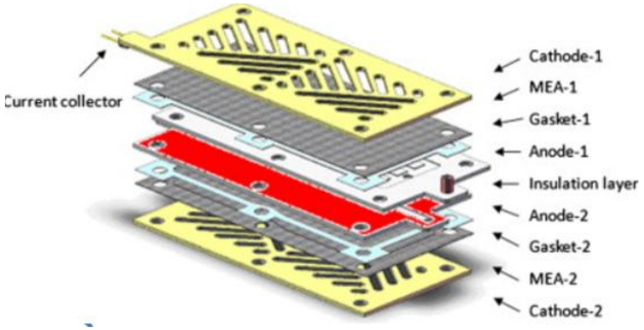
01 Closed-type fuel cell

Requires an external air supply system for the cathode, resulting in a more complete but more complex system.

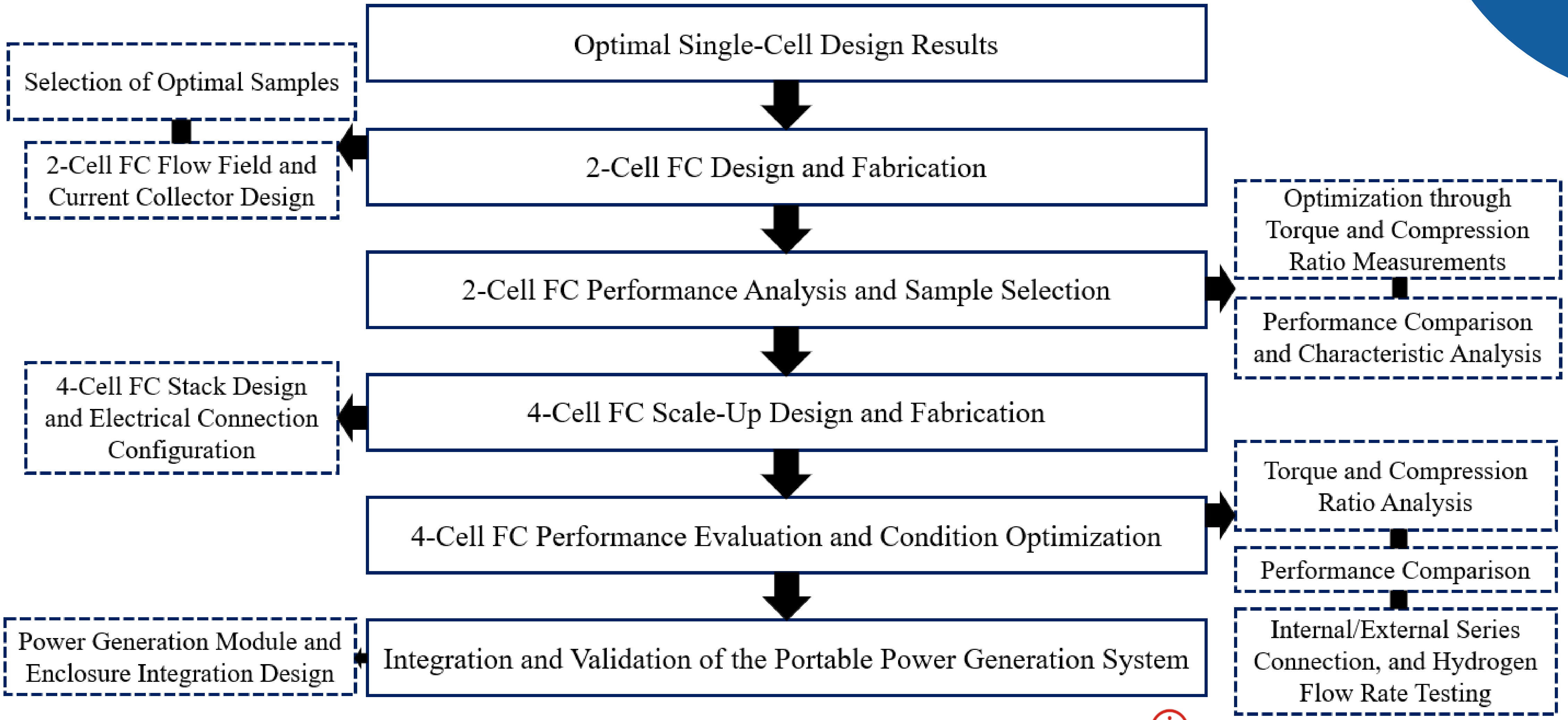
02 Open-cathode fuel cell

Hydrogen is supplied to the anode, while the cathode is directly exposed to ambient air, enabling a lightweight and portable system design.





Experimental procedure



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Single-Cell Design and Optimization

- Control Factors and Taguchi Method & Selection of the Six Optimal Designs -

Control Factors and Levels

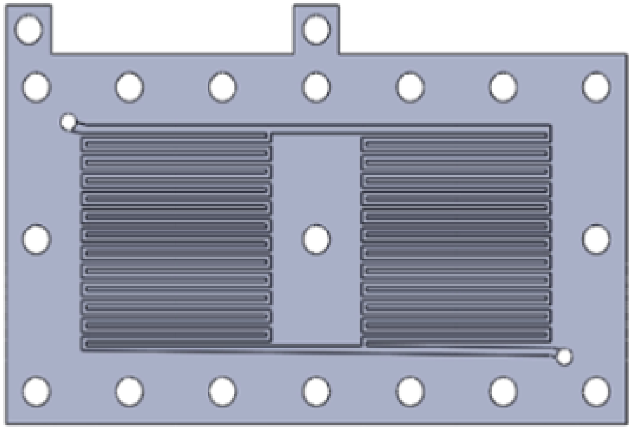
Factor	Parameter	Level 1	Level 2	Level 3
A	Substrate Thickness (mm)	0.25	0.40	0.65
B	Anode Opening Diameter (mm)	3.2	4.0	4.8
C	Anode Opening Ratio (%)	16	20	24
D	Cathode Opening Diameter (mm)	3.2	4.0	4.8
E	Cathode Opening Ratio (%)	16	20	24
F	Gasket Thickness (%)	50	37.5	25

Case No.	Material Thickness (mm)	Anode Opening Diameter (mm)	Anode Opening Ratio (%)	Cathode Opening Diameter (mm)	Cathode Opening Ratio (%)	Gasket Thickness (%)
1	0.40	3.2	20	4.8	24	0.34
2	0.40	4.0	24	3.2	24	0.35
3	0.40	4.8	16	4.0	24	0.34
4	0.65	4.0	16	4.8	20	0.43
5	0.65	4.8	20	3.2	20	0.43
6	0.65	4.0	16	4.8	24	0.43

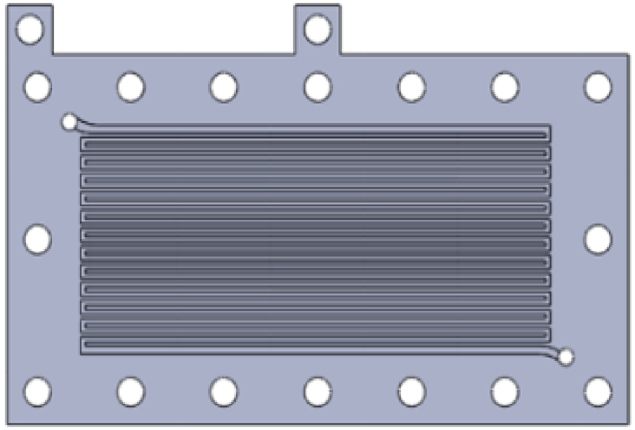
The case with better single cell performance was selected as the basis for the fabrication of the 2-cell, which was then subjected to experimental testing.

2-Cell FC

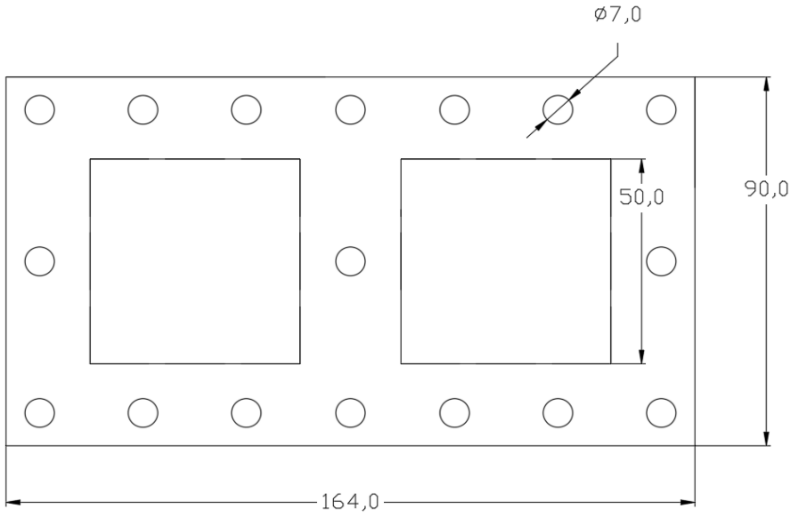
- Flow Channel Comparison & Current Collector Comparison -



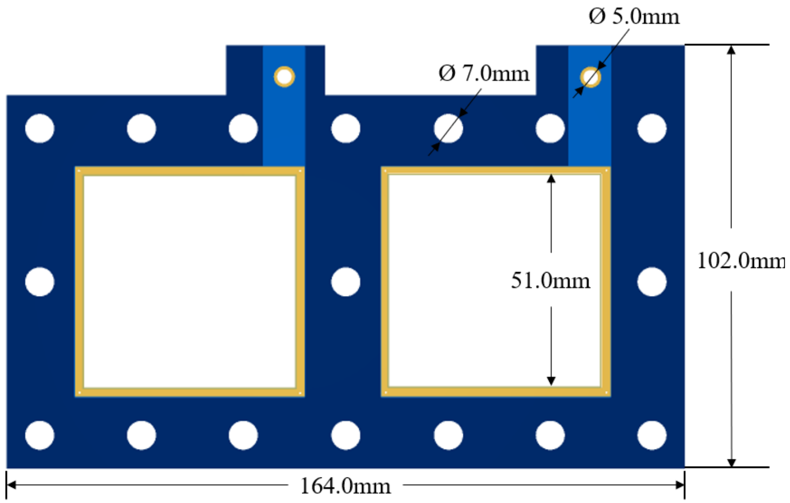
Parallel flow field



Single serpentine flow field



FR-4 type current collector



PCB type current collector

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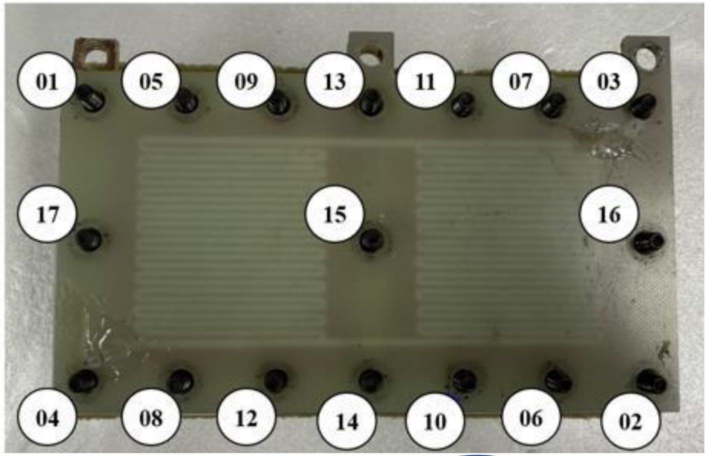
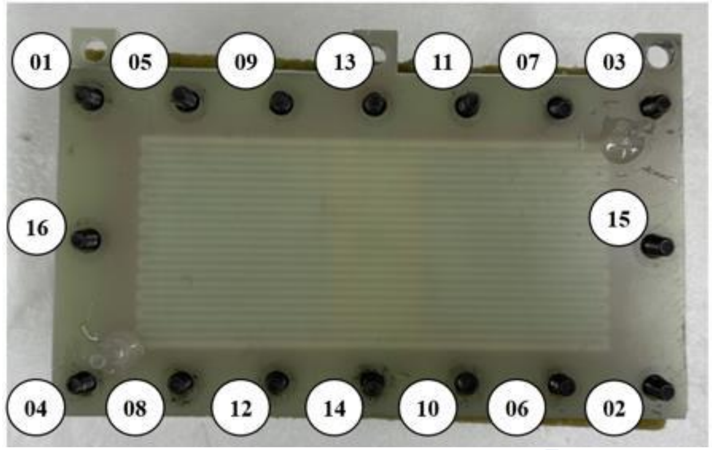
2-Cell FC

- Assembly and Compression & Force Effect of Applied Torque -

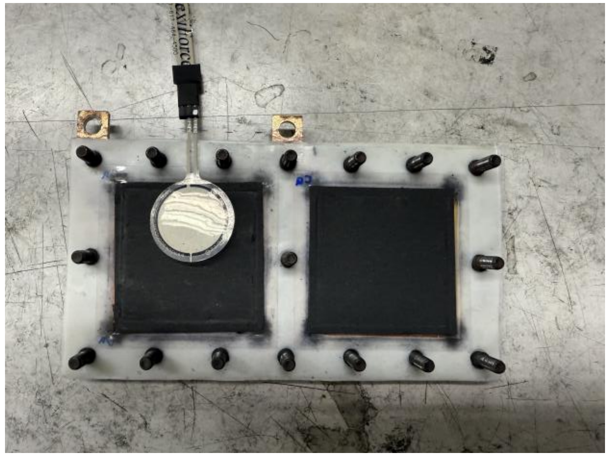


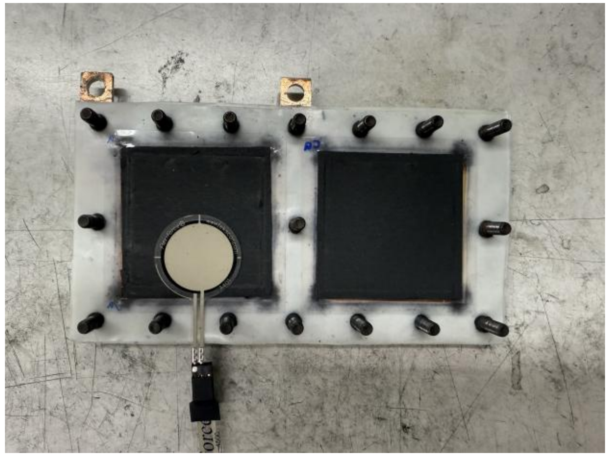
Parallel flow field



Single serpentine flow field

Taking the Parallel flow fieldcase as an example, clamping force measurements in the cell reaction region were performed using a thin-film pressure sensor. The Memstec FlexiForce ELF System, utilizing the FlexiForce A401 sensor (sensing area: 5.06 cm^2), was used for this purpose. The clamping force was measured at stepwise applied torques of 4, 8,12,16, and 20 kgf·cm for each individual fastening position.





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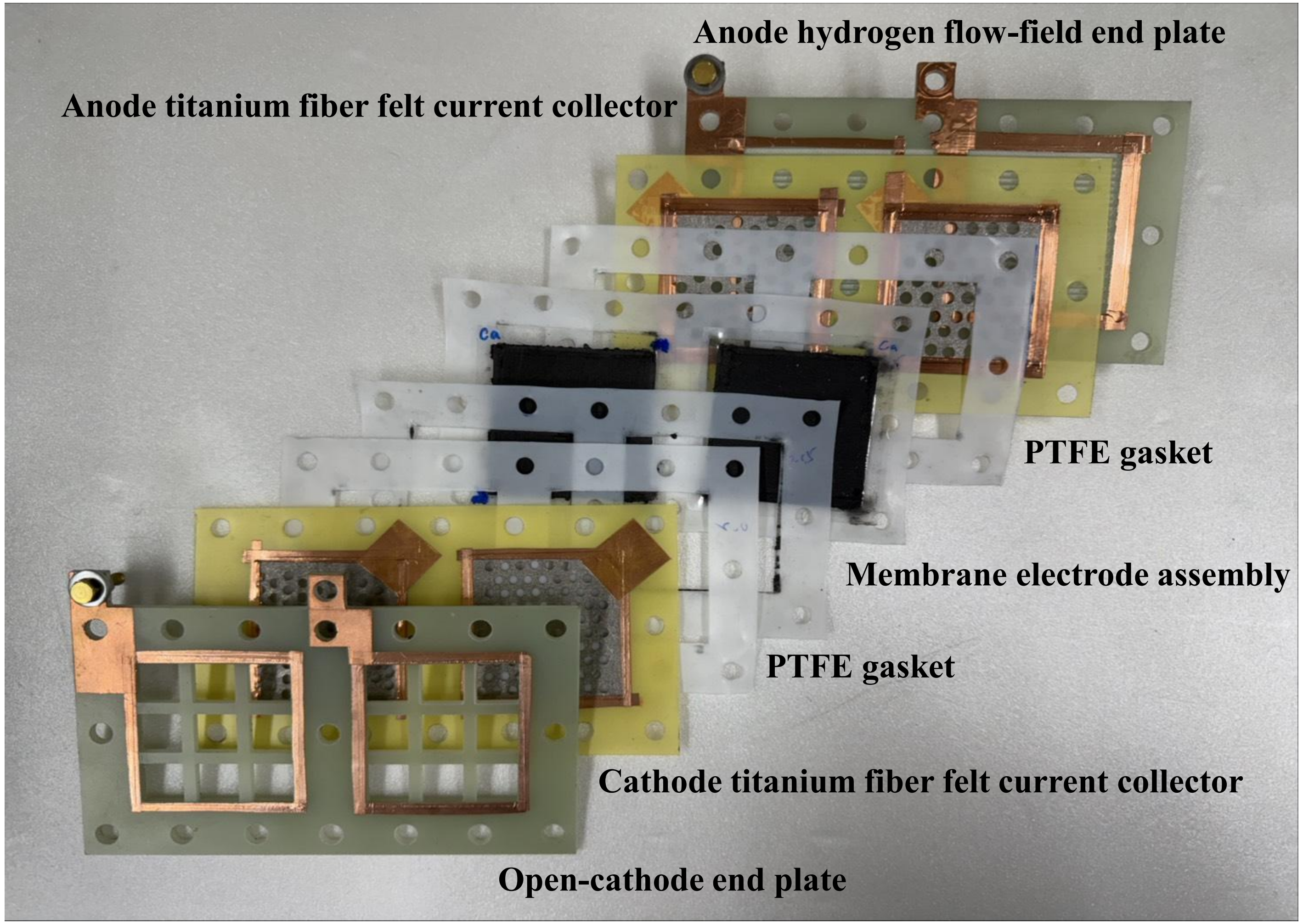
2-Cell FC

- Design & Experimental Setup -



Test Conditions

Parameter	Value
Fuel Supply (Anode/Cathode)	Pure H_2 / Air
Anode Fuel Flow Rate (sccm)	300
Cathode Configuration	Open Cathode
Air Supply	Fan
Fuel Supply Temperature (°C)	Room Temperature
Relative Humidity (%)	Not Controlled

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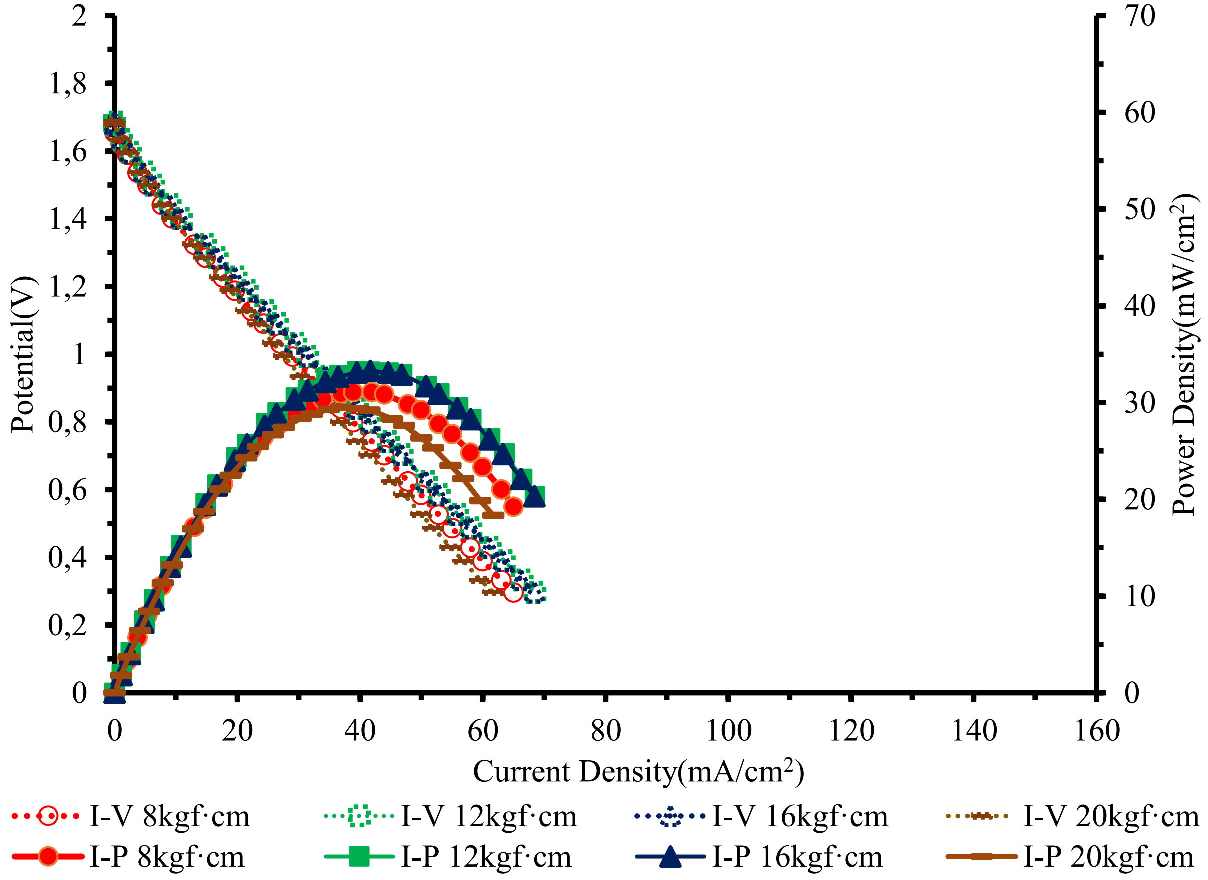
2-Cell FC

- Comparison of Applied Torque and Clamping Force -

Torque screwdriver value (kgf·cm)	Unit(kgf)	
	Upper Half of Single-Serpentine Flow Channel	Lower Half of Single-Serpentine Flow Channel
4kgf·cm	0.23	6.9
8kgf·cm	1.21	11.74
12kgf·cm	1.46	12.87
16kgf·cm	1.30	13.2
20kgf·cm	1.05	13.65



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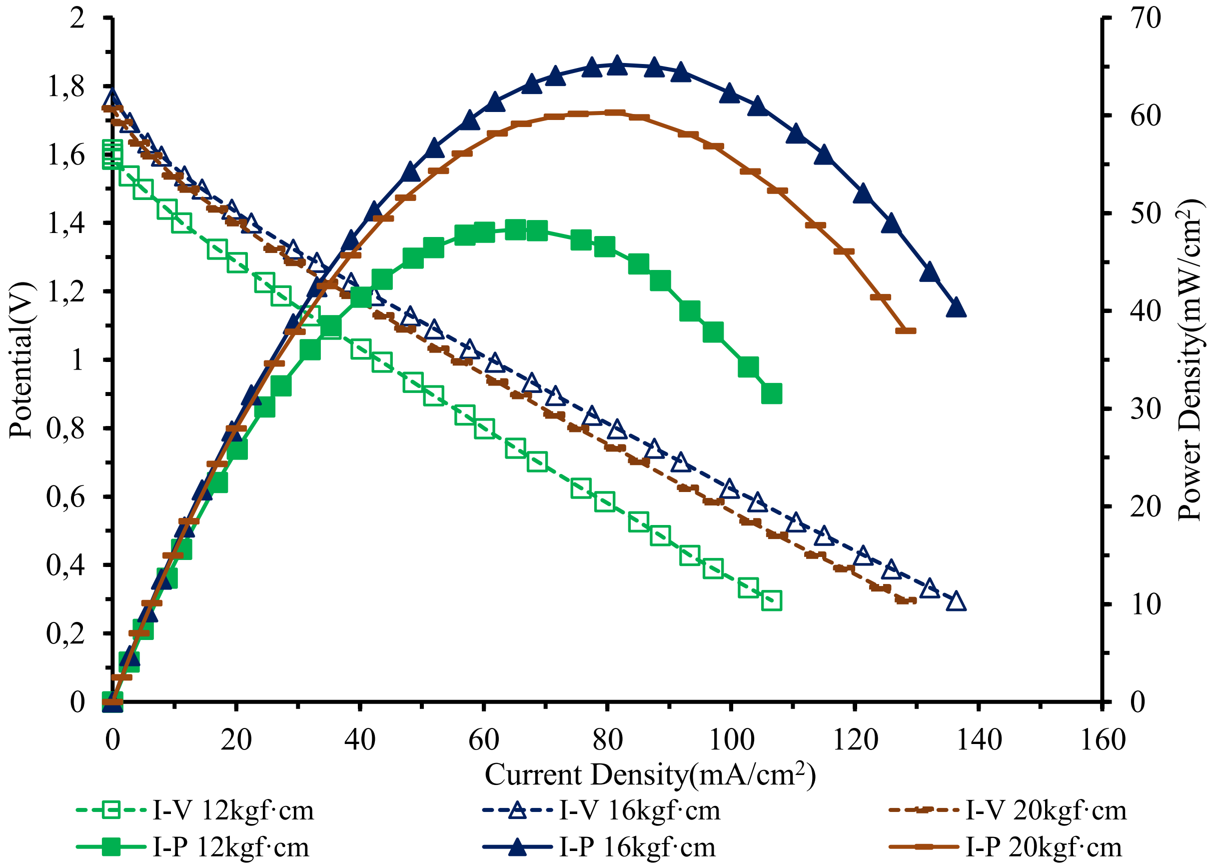
2-Cell FC

- Comparison of Applied Torque and Clamping Force -

Torque screwdriver value (kgf·cm)	Unit(kgf)	
	Upper Part of Parallel Flow Channel	Lower Part of Parallel Flow Channel
4kgf·cm	5.24	11.16
8kgf·cm	6.32	14.20
12kgf·cm	6.70	14.82
16kgf·cm	6.84	14.83
20kgf·cm	6.28	14.23



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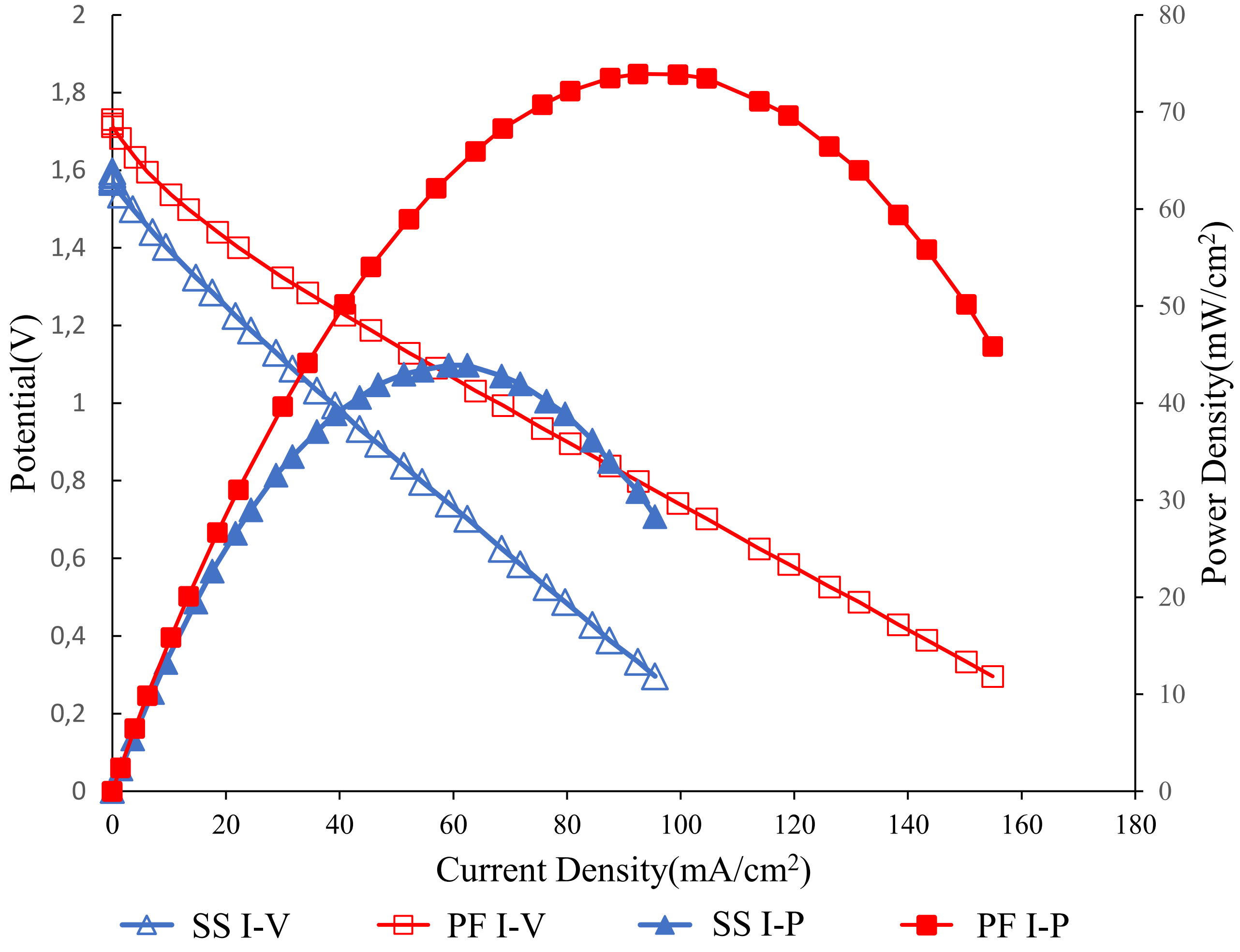
2-Cell FC

- Flow Channel Comparison -



Maximum Power Point Data

	Single serpentine flow field	Parallel flow field
Case No.	Case 4	Case 6
Active Area (cm^2)	50	
Current Density (mA/cm^2)	62.5	92.52
Power Density (mW/cm^2)	43.9	73.92

Case 4 (Single serpentine) and Case 6 (parallel) were adopted for all subsequent experiments.

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2-Cell FC

- Comparison of Applied Torque and Clamping Force -

PCB Current Collector under Different Applied Torques

Torque screwdriver value (kgf·cm)	Unit(kgf)			
	Upper Half of Single-Serpentine Flow Channel	Lower Half of Single-Serpentine Flow Channel	Upper Half of Parallel Flow Channel	Lower Half of Parallel Flow Channel
4kgf·cm	0.73	1.13	4.55	6.84
8kgf·cm	1.30	1.30	6.05	9.74
12kgf·cm	1.21	1.46	6.54	10.61
16kgf·cm	1.13	1.21	6.45	10.88
20kgf·cm	1.21	1.05	6.22	10.52

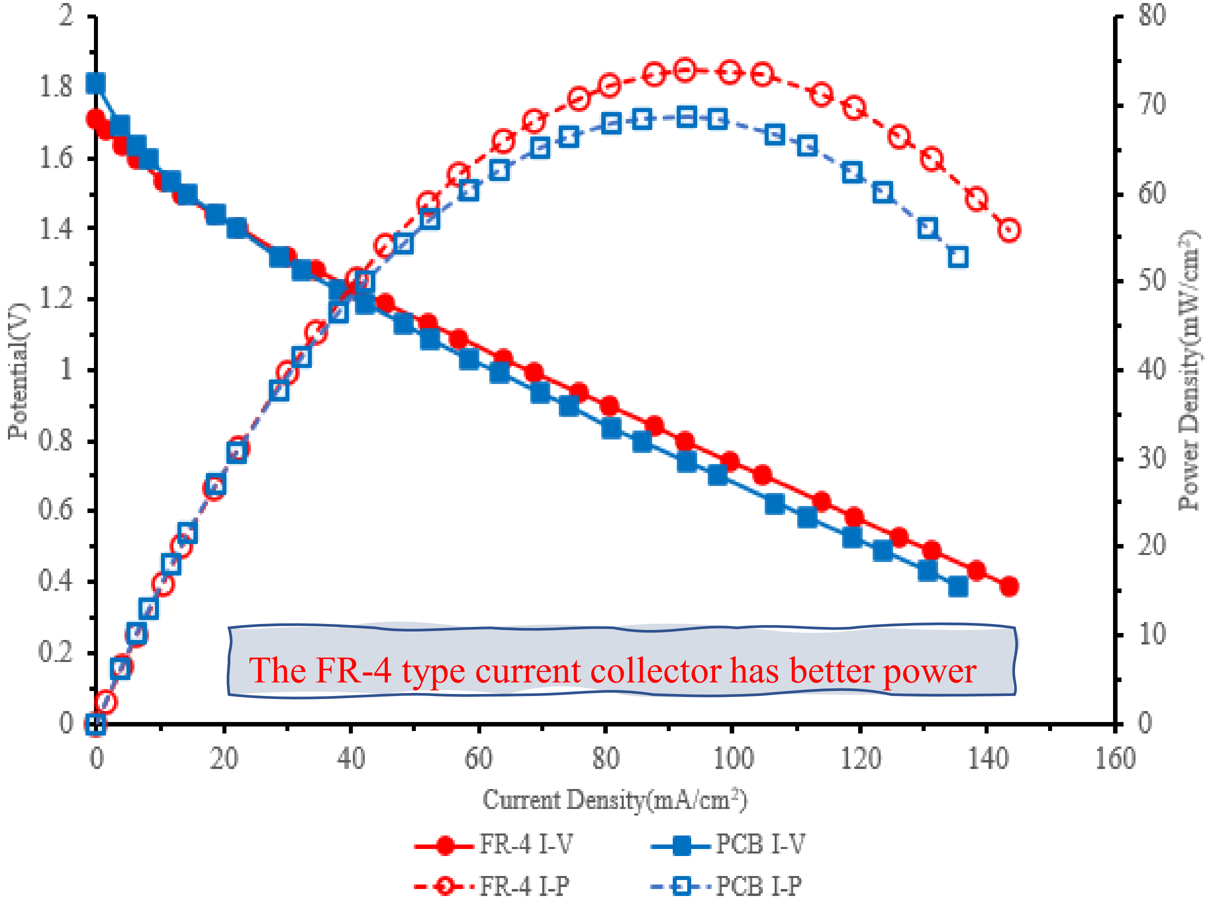
FR-4 Current Collector under Different Applied Torques

Torque screwdriver value (kgf·cm)	Unit(kgf)	
	Upper Half of Single-Serpentine Flow Channel	Lower Half of Single-Serpentine Flow Channel
4kgf·cm	0.23	6.9
8kgf·cm	1.21	11.74
12kgf·cm	1.46	12.87
16kgf·cm	1.30	13.2
20kgf·cm	1.05	13.65

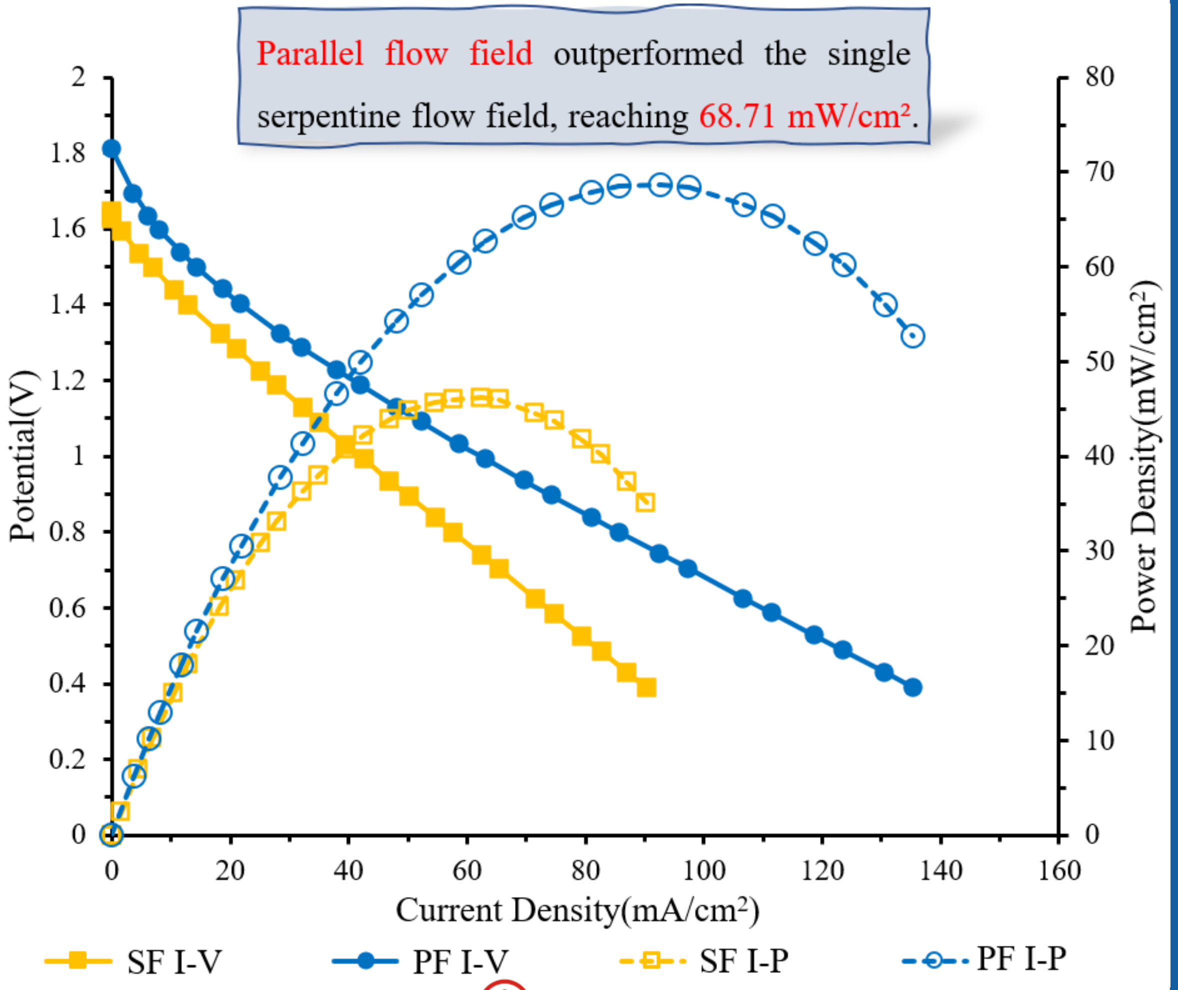
The PCB current collector has an advantage in achieving a more uniform clamping force distribution.

2-Cell FC

- Current Collector Comparison & Flow Channel Comparison -



	FR-4 type current collector	PCB type current collector
Maximum Power Density (mW/cm²)	73.92	68.71



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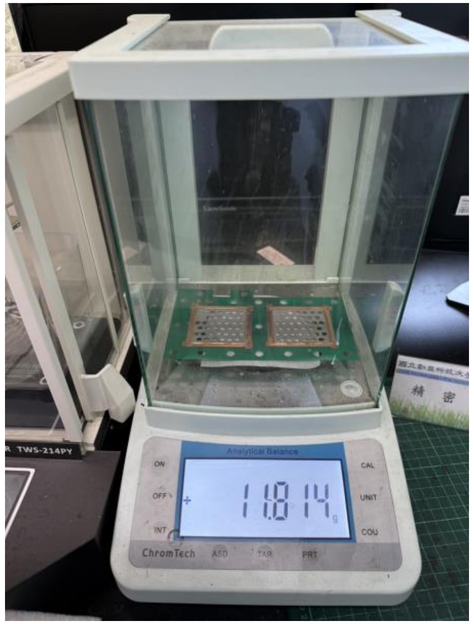
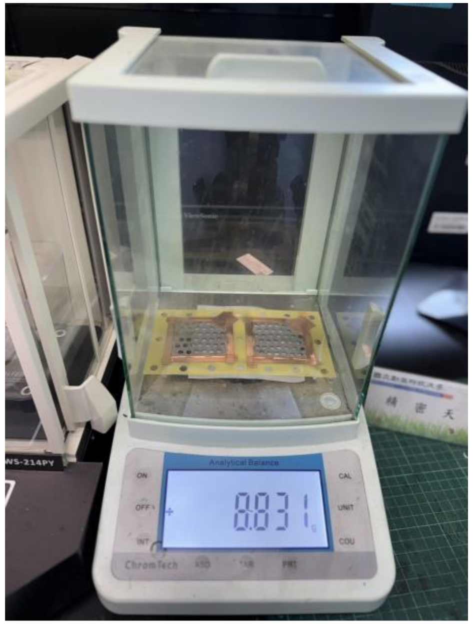
2-Cell FC

- Weight Comparison -

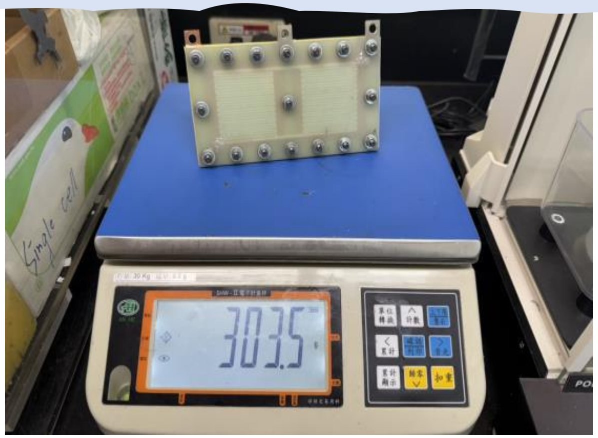


PCB type current collector weight

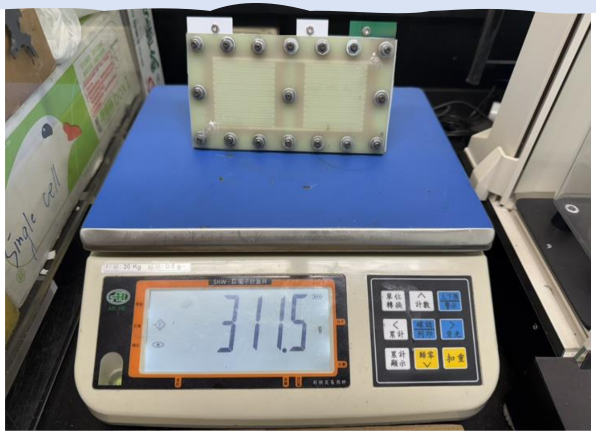


FR-4 type current collector weight

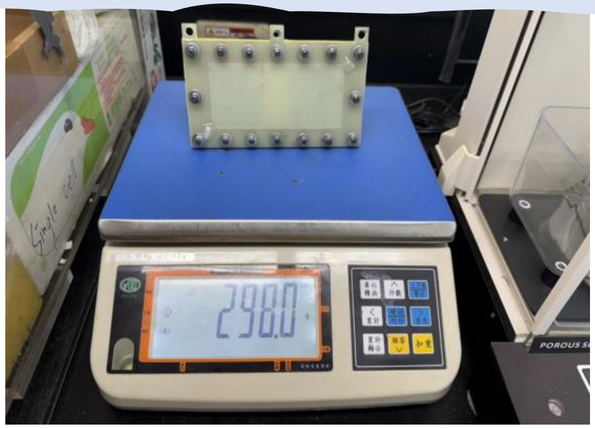
FR-4 type FC weight (Parallel flow field)



PCB type FC weight (Parallel flow field)



FR-4 type FC weight (Single serpentine flow field)



The PCB current collector was slightly heavier than the FR-4 current collector.

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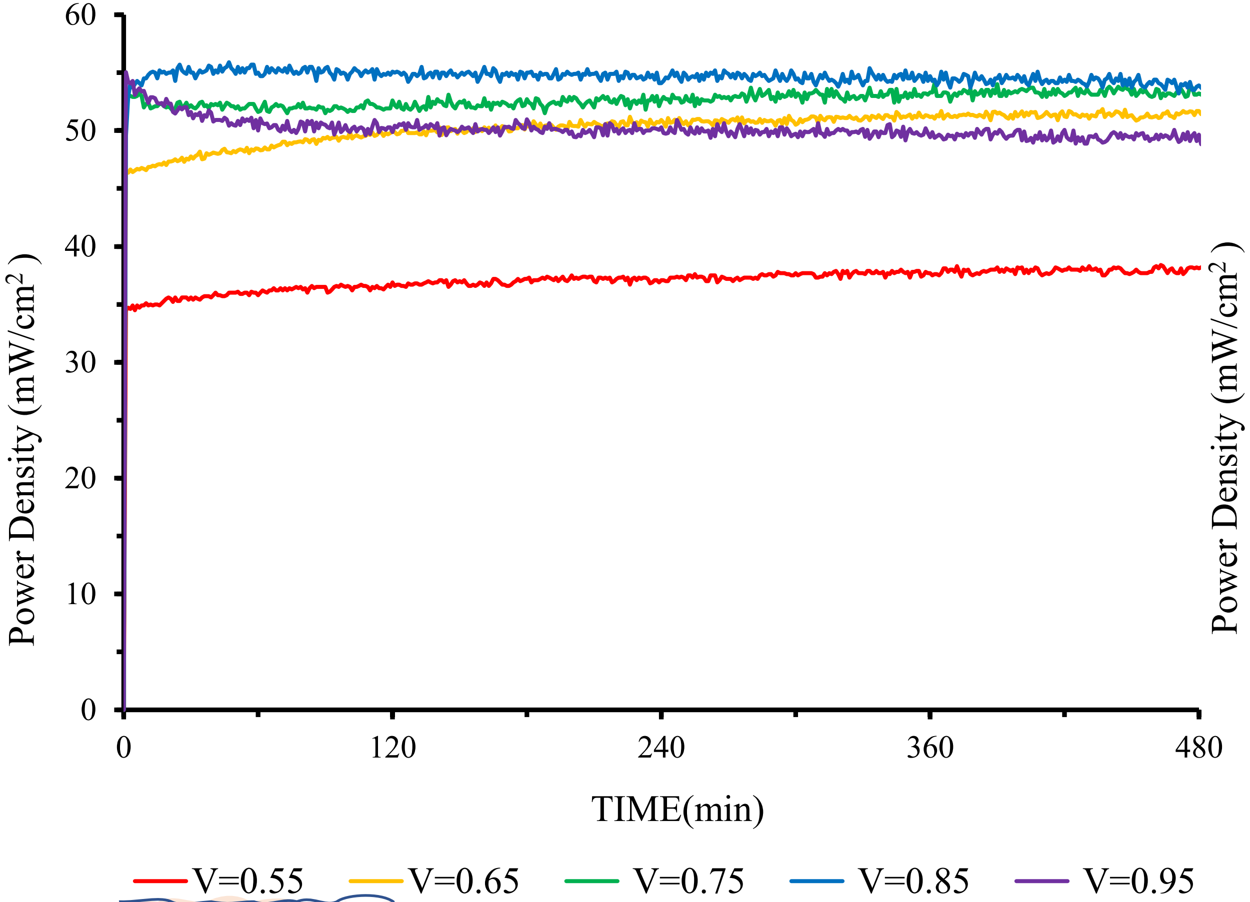
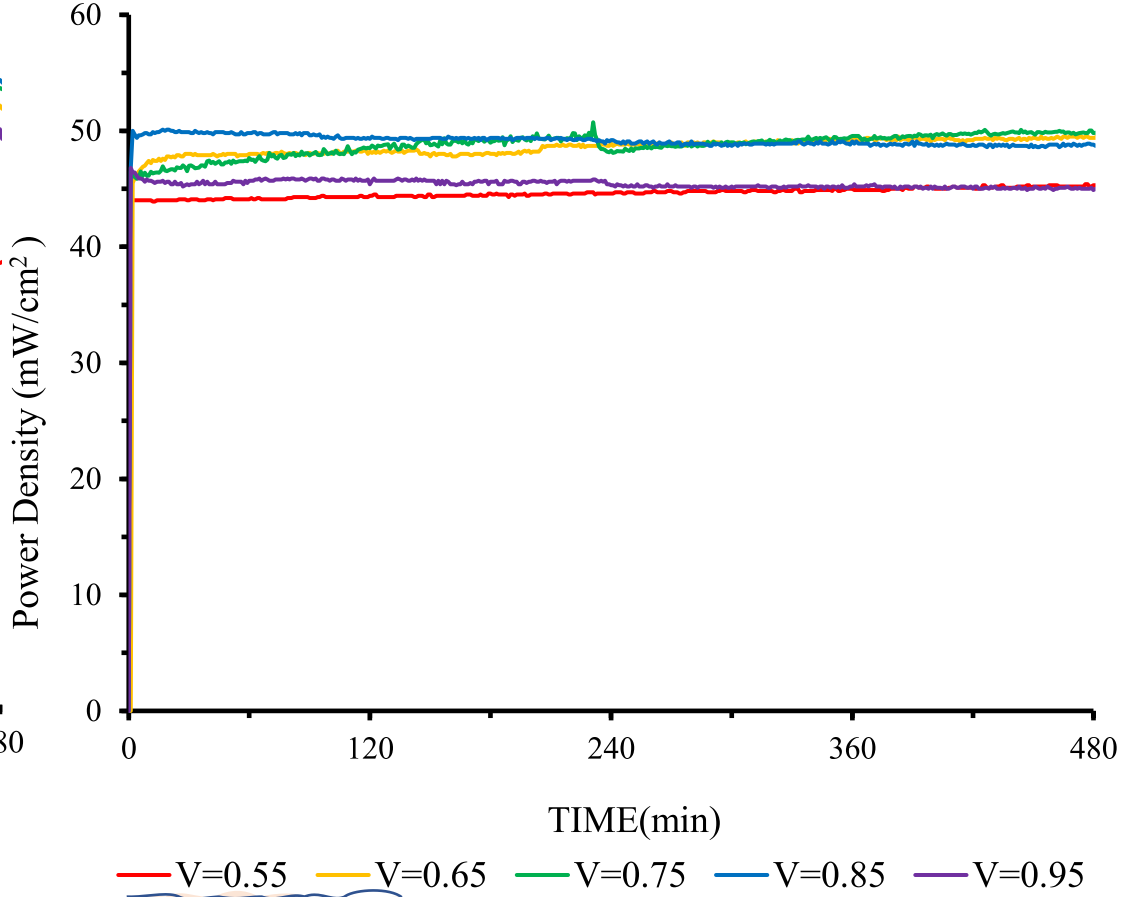
2-Cell FC

- Stability Test -



FR-4 2-Cell FC



PCB 2-Cell FC

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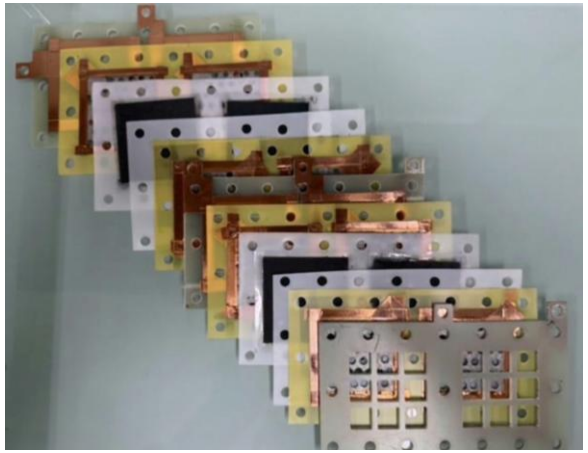
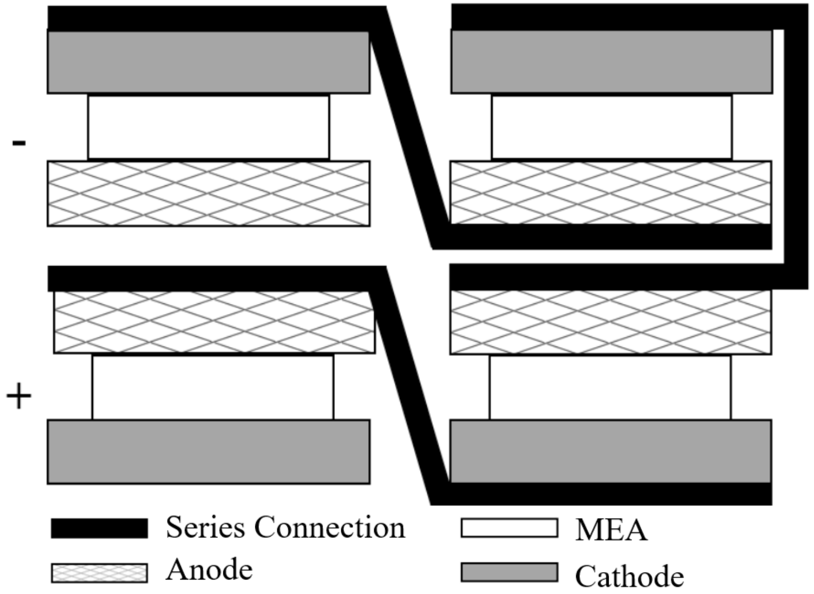
4-Cell FC

- Design & Electrical Connection & Experimental Setup -





Test Conditions

Parameter	Value
Fuel Supply (Anode/Cathode)	Pure H_2 / Air
Anode Fuel Flow Rate (sccm)	Determined from subsequent tests
Air Supply	2 Fans
Cathode Air Flow Rate (LPM)	2120
Fuel Supply Temperature (˚C)	25 ± 2 (Room Temperature)
Relative Humidity (%)	Anode < 5 Cathode 65 ± 10

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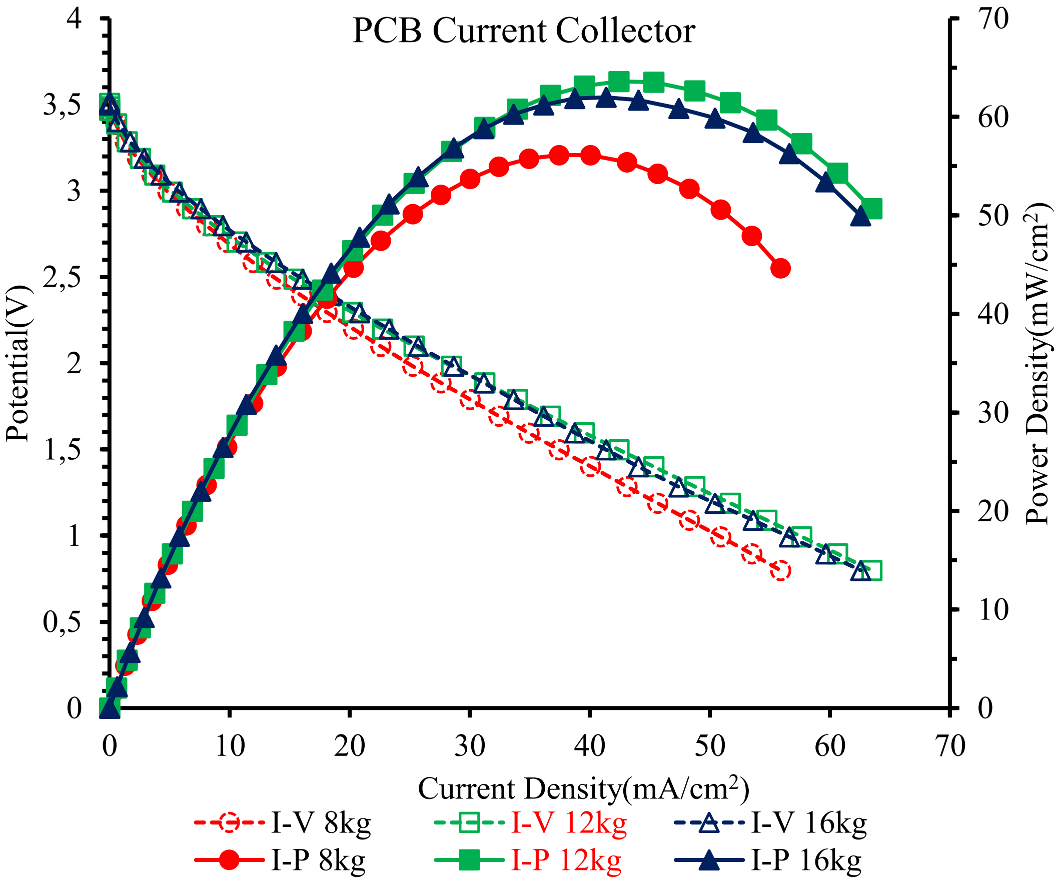
4-Cell FC

- Comparison of Applied Torque and Clamping Force -

Clamping Force of 4-Cell FC with Different Current Collectors

Torque screwdriver value (kgf·cm)	Unit(kgf)			
	FR-4 Current Collector – Upper Part	FR-4 Current Collector – Lower Part	PCB Current Collector – Upper Part	PCB Current Collector – Lower Part
4kgf·cm	6.91	10.72	7.41	8.34
8kgf·cm	8.67	15.54	9.80	14.06
12kgf·cm	6.90	16.91	10.64	18.51
16kgf·cm	10.72	18.20	10.93	20.35
20kgf·cm	11.37	19.20	11.14	20.49

The compressive force sensor reached a maximum value of 20.49 kgf



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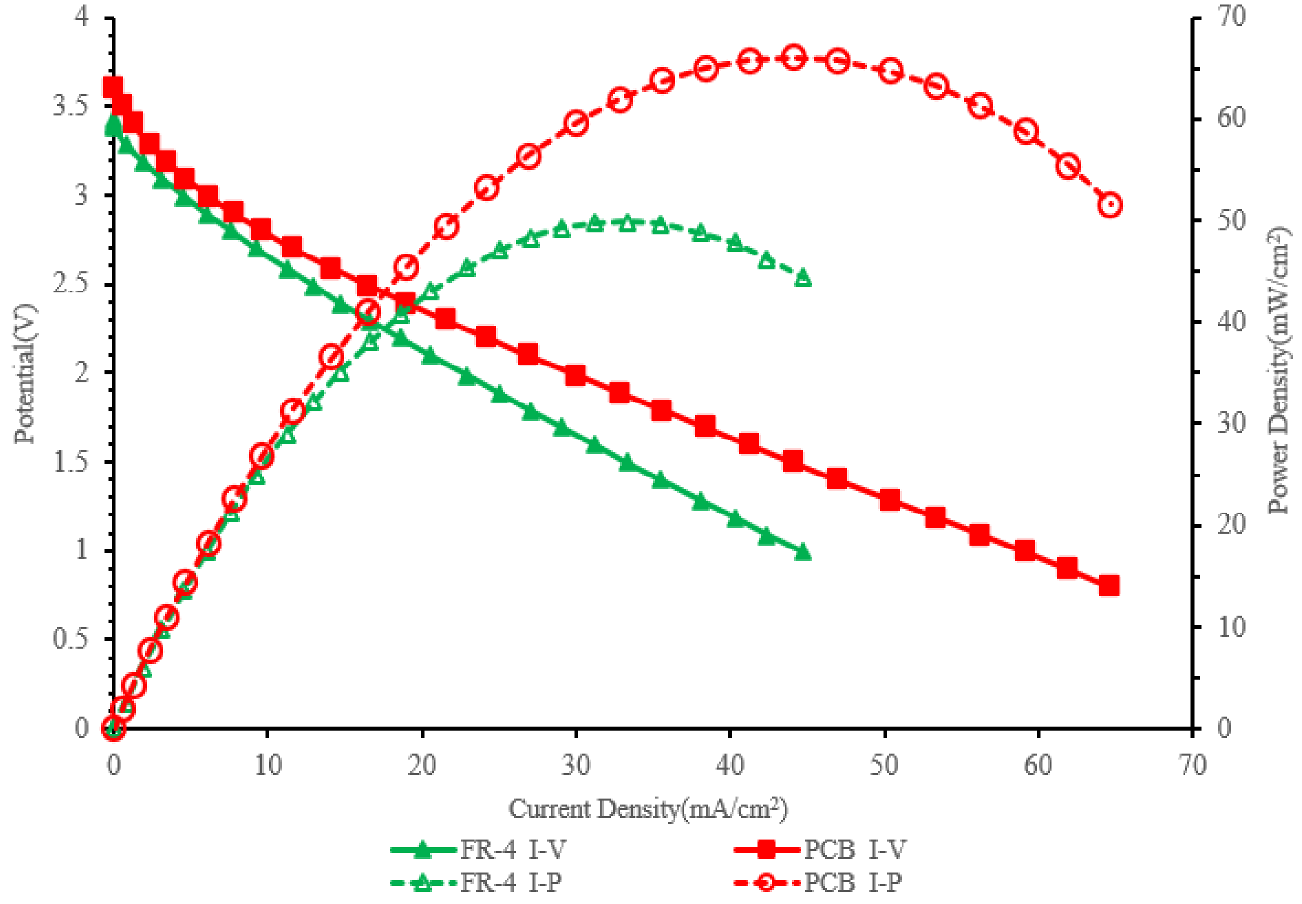
4-Cell FC

- Performance Comparison -



The PCB current collector significantly outperforms the FR-4 current collector in terms of maximum power density, with a difference of approximately 16 mW/cm².

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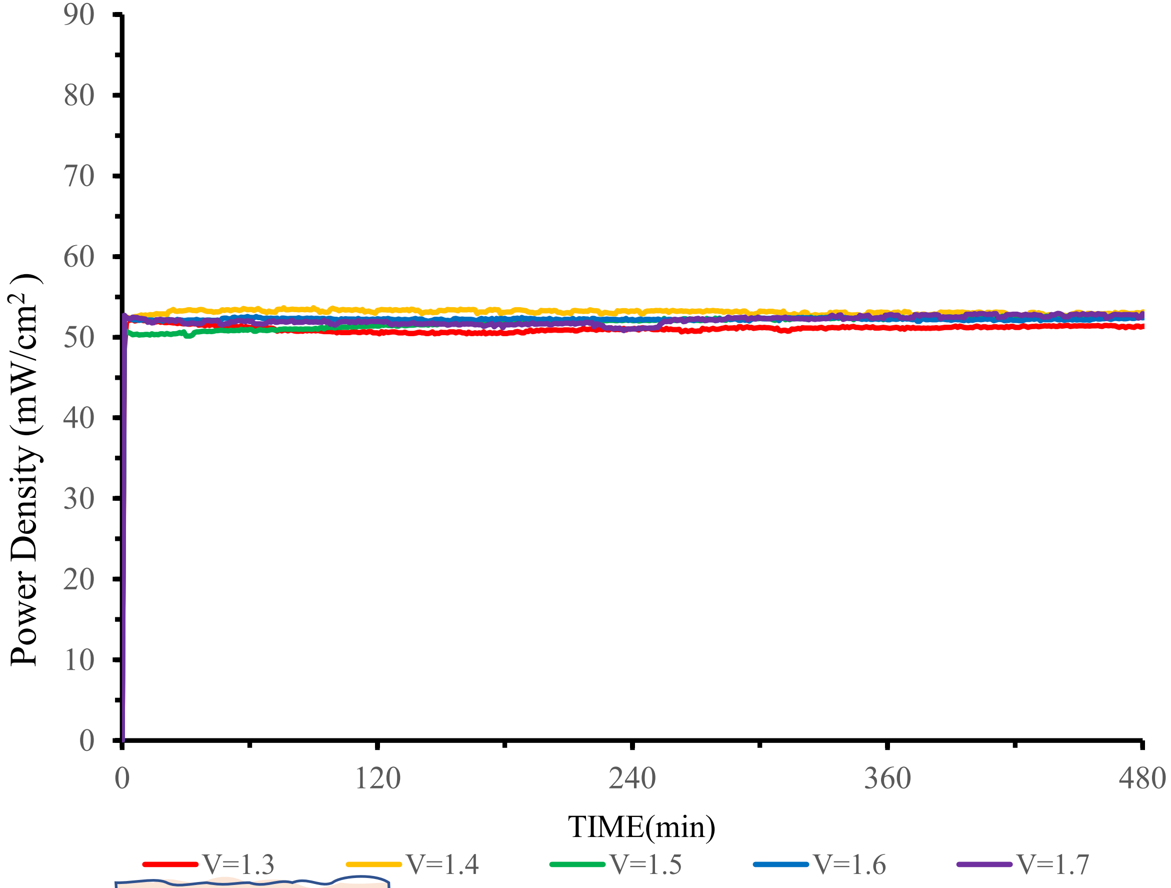
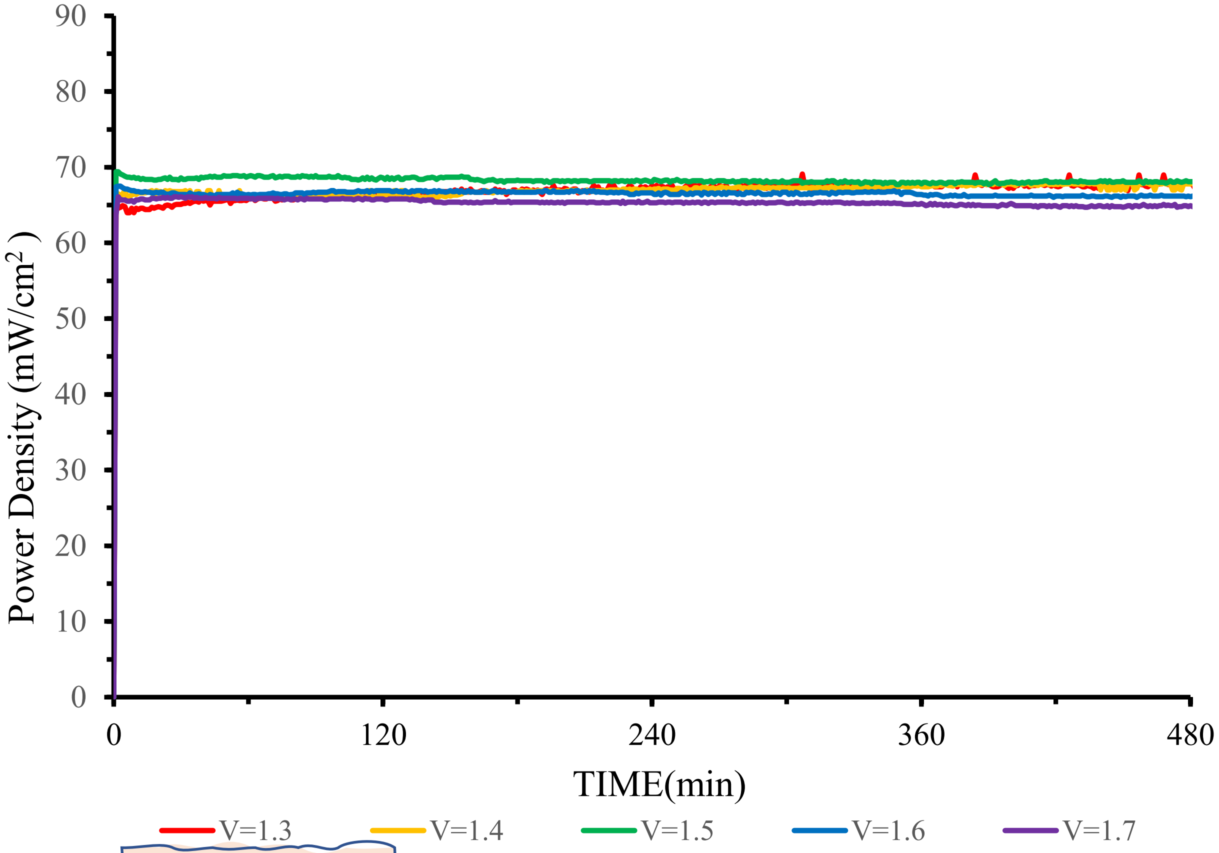
4-Cell FC

- Stability Test -



FR-4 4-Cell FC



PCB 4-Cell FC

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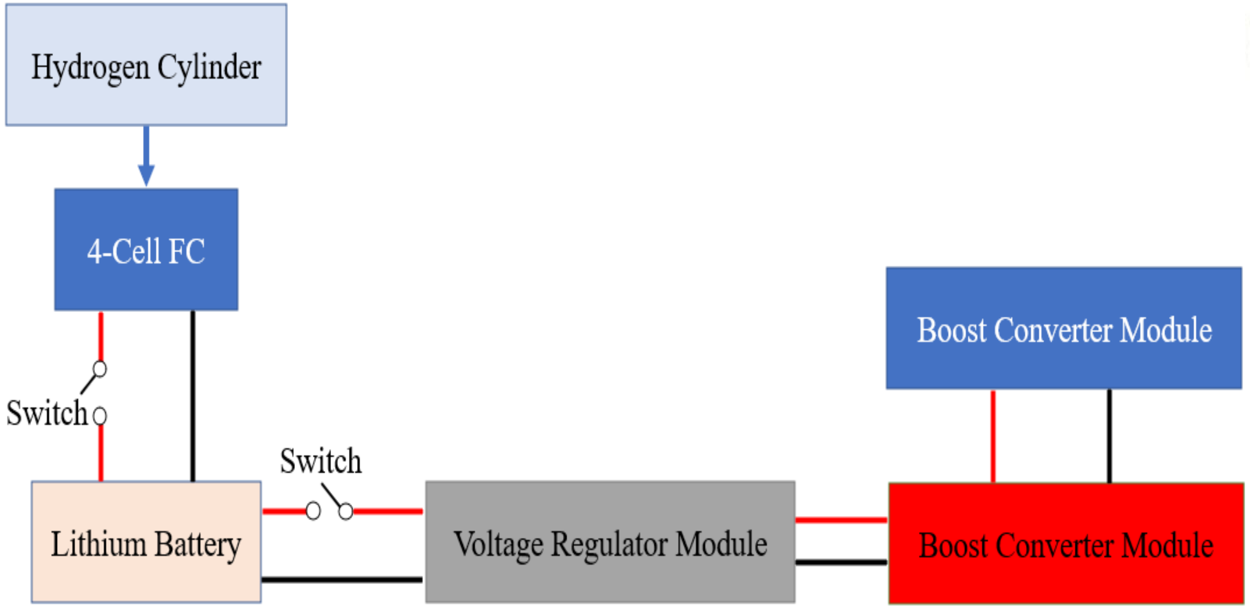
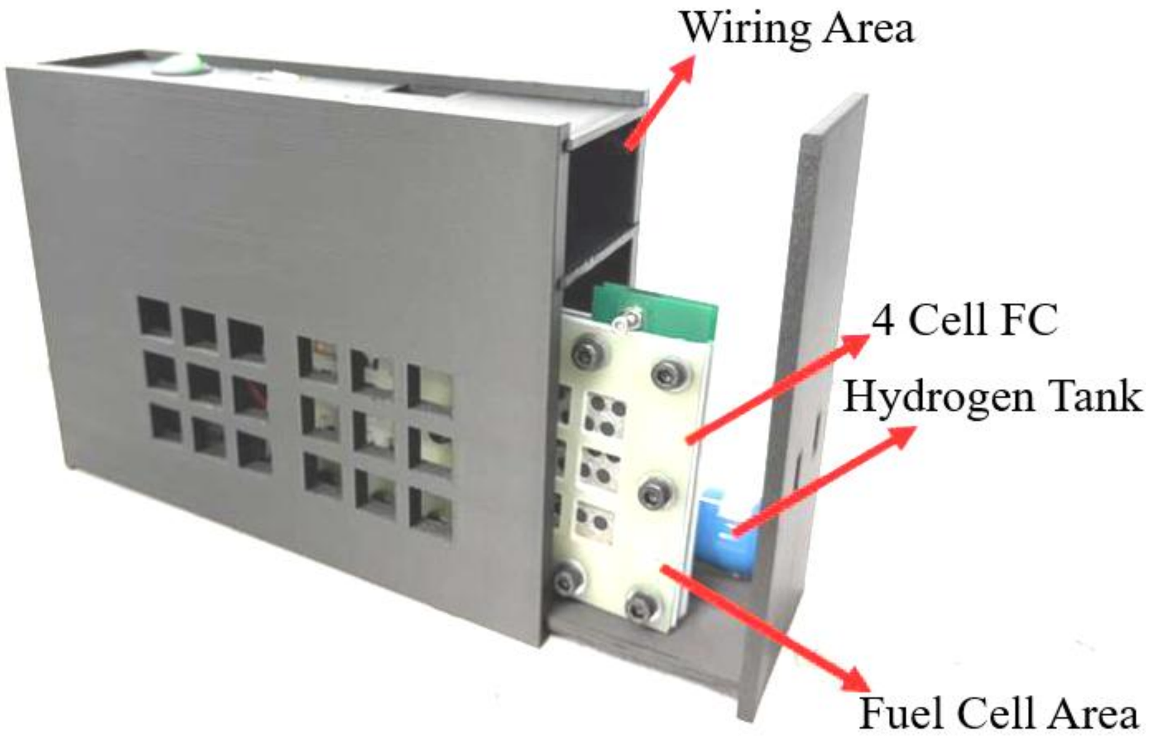
Portable Power Generation System

- System Design -





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Portable Power Generation System

- Power Generation Performance Test -

Conclusions and Future Work

- Conclusions & Future Work -

Conclusions

1. The single-cell optimization results were successfully extended to 2-cell and 4-cell fuel cell and integrated into a portable power generation device.
2. The optimal compression conditions differed between the 2-cell and 4-cell configurations, while the parallel flow field achieved superior performance in the 2-cell.
3. The PCB current collector exhibited better performance and stability in the 4-cell configuration and was selected for the portable power generation system.
4. The external-series PCB 4-cell successfully powered a smartphone and a small fan, demonstrating its potential for portable power applications.

Future Work

1. **Explore additional flow field designs :**
   Investigate different flow field configurations.
2. **Improve compression-force measurement :**
   Improve measurement accuracy with numerical simulation.
3. **Evaluate long-term durability :**
   Investigate long-term degradation and stability.
4. **Optimize module assembly :**
   Reduce module weight while maintaining sufficient compression.
5. **Enhance system control :**
   Develop automatic control based on load and battery status.

Thank you for your attention