ICCM 23
International Conference
on Composite Materials
30 July – 4 August

Ultra-thin Attachable Bipolar plate for High-Performance VRFB

PRESENTER

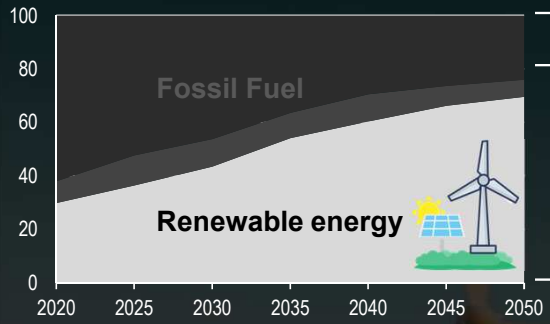
Jae-Moon Jeong

PI: Seong Su Kim

MECHANICAL DESIGN LAB. with
ADVANCED MATERIALS

KAIST

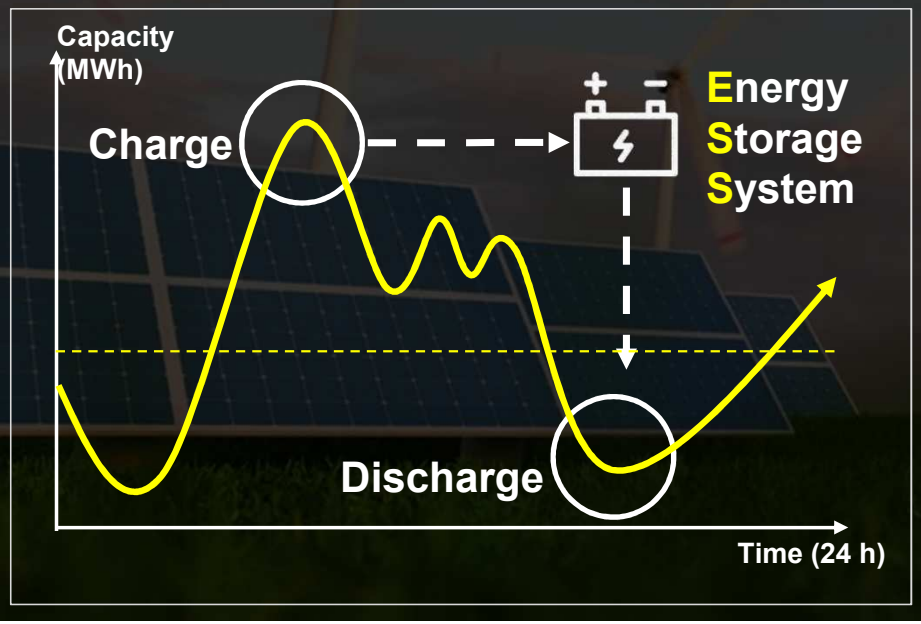
< Global Electricity Production >



	2020	2030	2040	2050
Fossil Fuel (%)	62	50	37	30
Nuclear (%)	10	9	8	7
Renewable (%)	28	41	55	63

Source : BloombergNEF New Energy Outlook 2020

< Production instability >



*QC = Quick Charging System

Biweekly Meeting

1. Risk of Fire and Explosion in the Li-ion based ESS

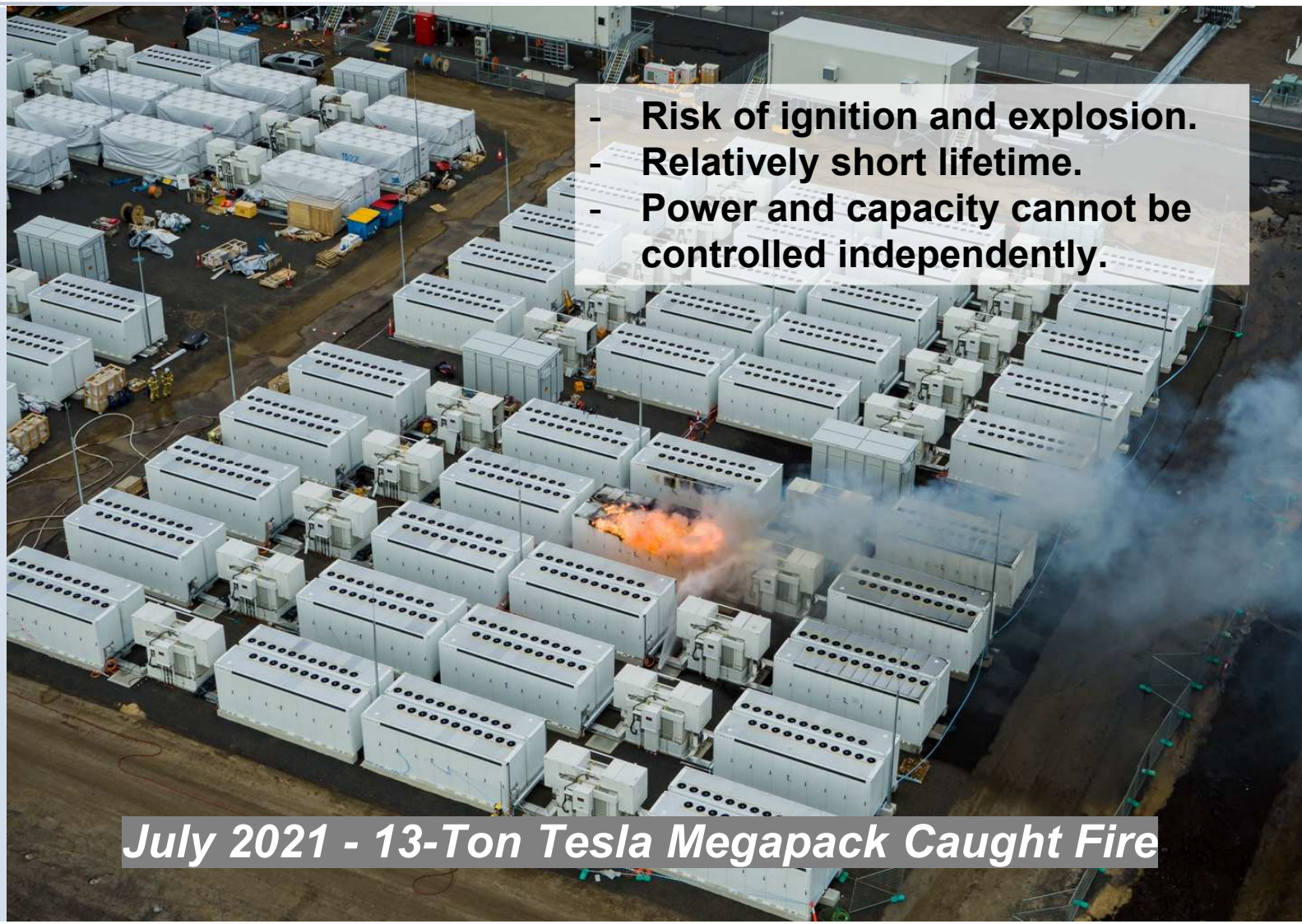
Li-ion Battery

Non-Aqueous Electrolyte

ESS Accident in Korea (2017-2022)

Total Facility		1,490 locations
Fire Incidents		35 locations
Production Break		777 locations

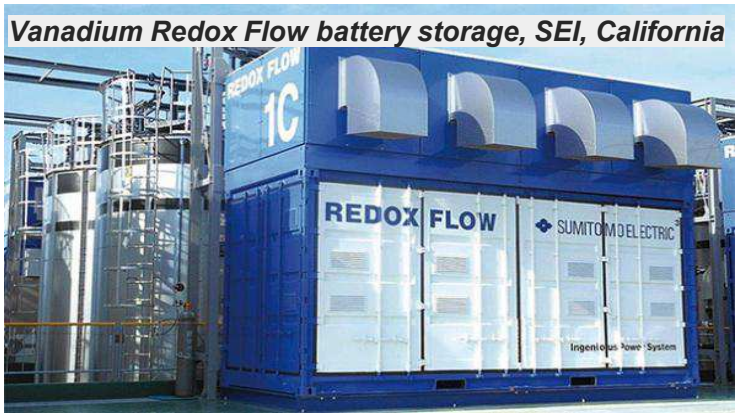
Source : Ministry of Trade, Industry and Energy.



- Risk of ignition and explosion.
- Relatively short lifetime.
- Power and capacity cannot be controlled independently.

July 2021 - 13-Ton Tesla Megapack Caught Fire

1. Vanadium Redox Flow Batteries (VRFBs)



Vanadium Redox Flow battery storage, SEI, California

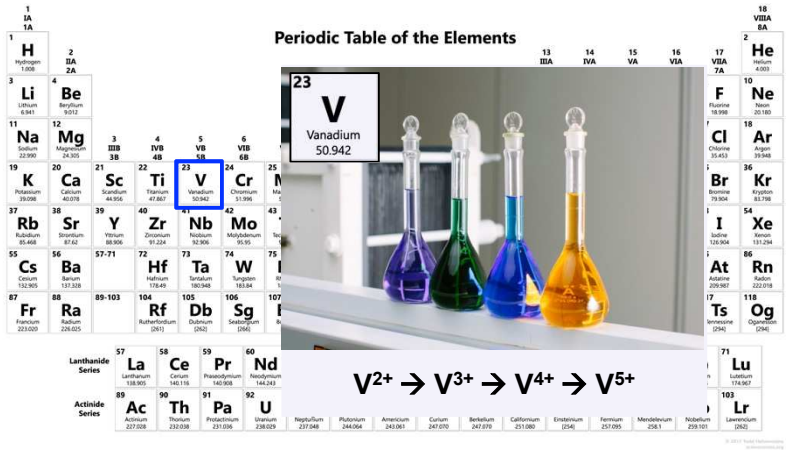
Fraunhofer ICT 2MW 20MWh VRFB electrolyte storage

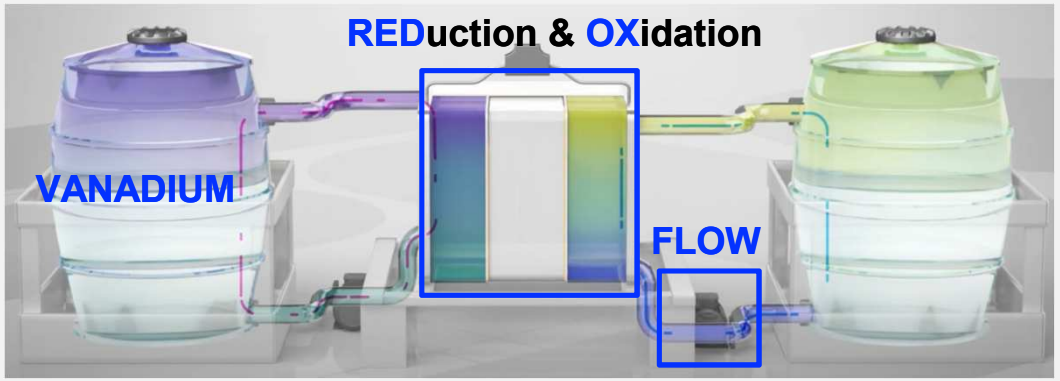
Safety of ESS	Lithium-ion	VRFB	Flooded Cell	Sodium Sulfur
Over-voltage	X	O	X	X
Arc-Flash	X	O	X	X
Fire	X	O	X	X

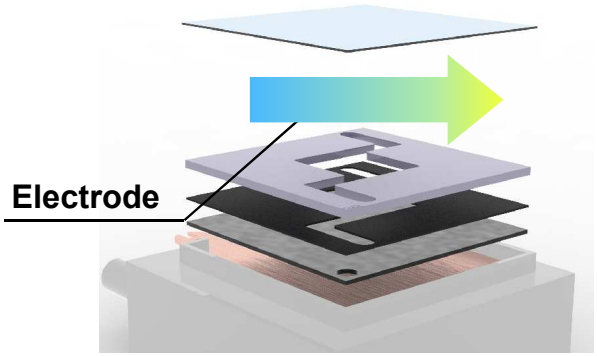
- No risk of explosion and ignition / High durability of over 20 years.
- High design flexibility in power and capacity.
- Low energy efficiency and density of VRFB.

1. Vanadium Redox Flow Batteries (VRFBs)

Principle and Schematic of VRFB





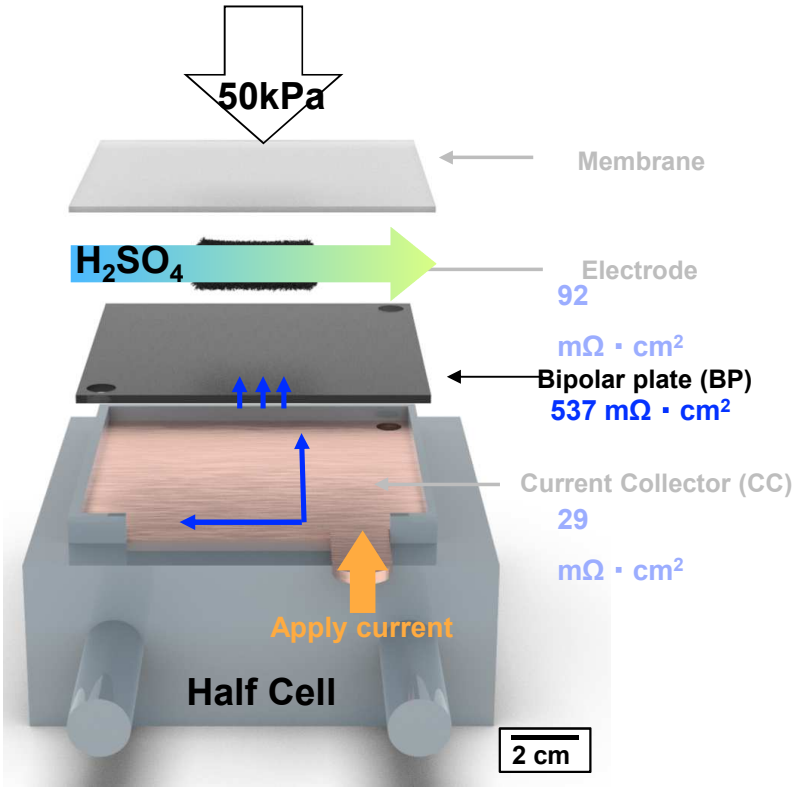


Porous media, Reactive area

- **Functional requirements of the electrode**
  - Large reactive area and reactivity
  - Excellent chemical durability
  - Low electrical resistance

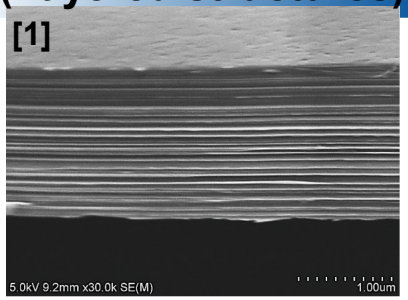
1. Vanadium Redox Flow Batteries (VRFBs)

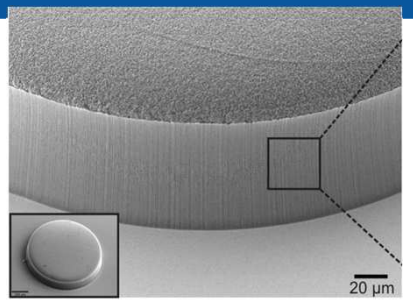
Half Cell of VRFB



- High electrical conductivity
- Low electrolyte permeability
- High rigidity (stiffness)

Graphite sheets + Epoxy (Layered structures) → CNT

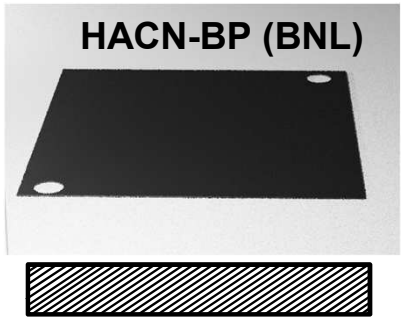




V_f = 20 ~ 35%

- Low ER* (In-plane direction)
- Low permeability / High rigidity
- High ER* (Through thickness direction)

Proposal



[1] Yost, Allison L., et al. *Microsystems & Nanoengineering* 1.1 (2015): 1-7.

*ER - Electrical resistance

1. Horizontally Aligned CNT Nanocomposite BP

40 times thinner
compared to
conventional BP

→ **High Energy Density**

Low ER
CNT connected from bottom
to top

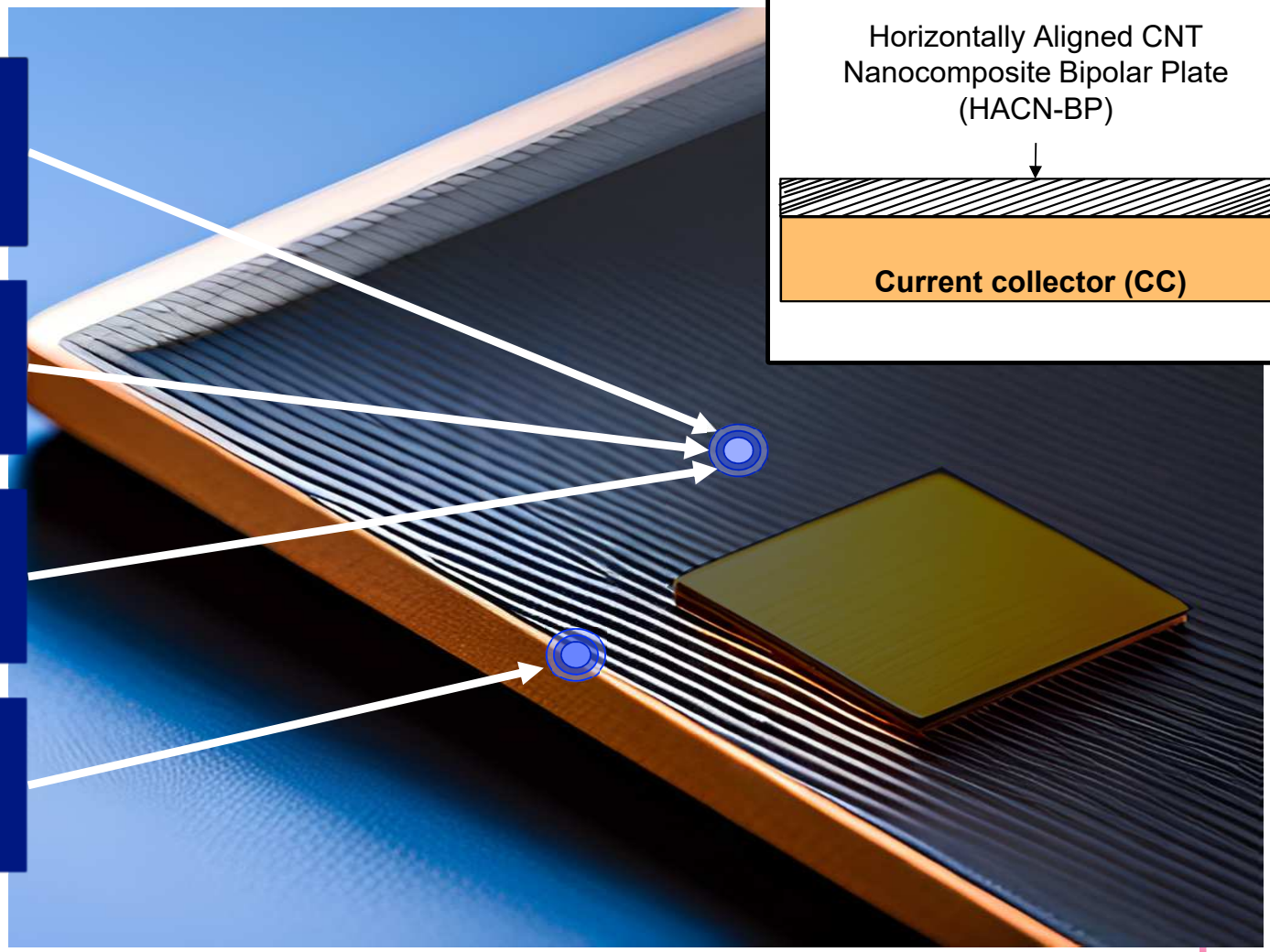
→ **High Energy Efficiency**

High CNT volume fraction (~50%)

→ **Low Permeability**

Attachable to the Current collector

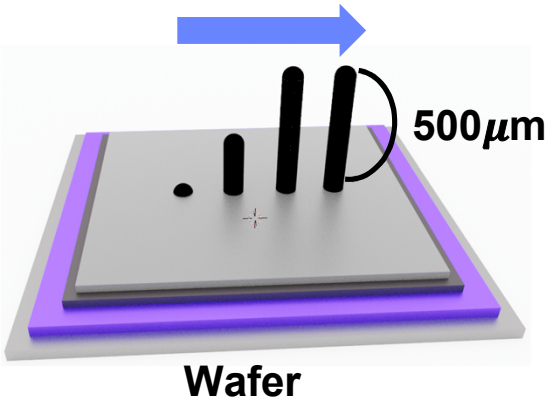
→ **Reduced Contact Resistance**



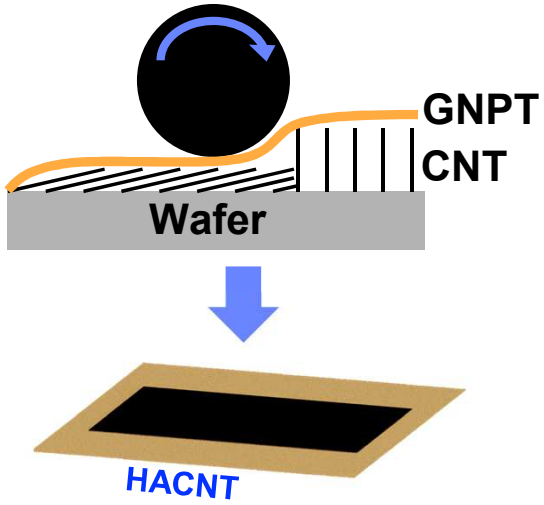
2. Experimental Procedures

2. Fabrication Process

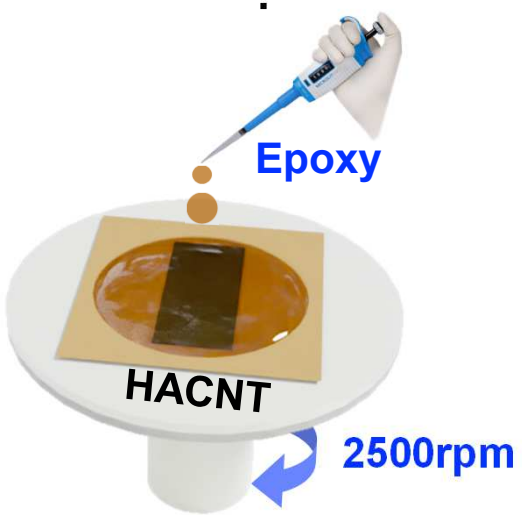
#1: VaCNT Growth ▶▶ **#2: Knocking down** ▶▶ **#3: Impregnation** ▶▶ **#4: Attach & Co-cure**



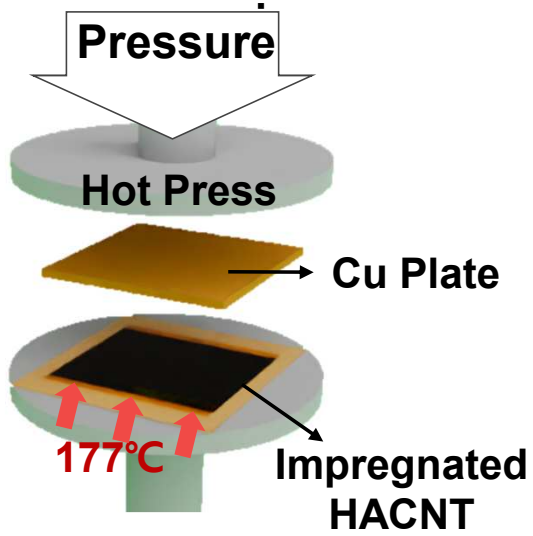
- **Materials coated on the Wafer**
  - Al_2O_3 – Buffer Layer
  - Fe – Catalysts
- **Preparation (Gas)**
  - Ethylene – Carbon Source
  - Hydrogen – Activated Catalysts
  - Helium – Carrier gas (Inert)
- **2" Furnace**



- **GNPT**
  - GNPT (PC-6, Precision coating, USA)
- **Horizontally Aligned CNT (HACNT)**
  - Knocked down by roller

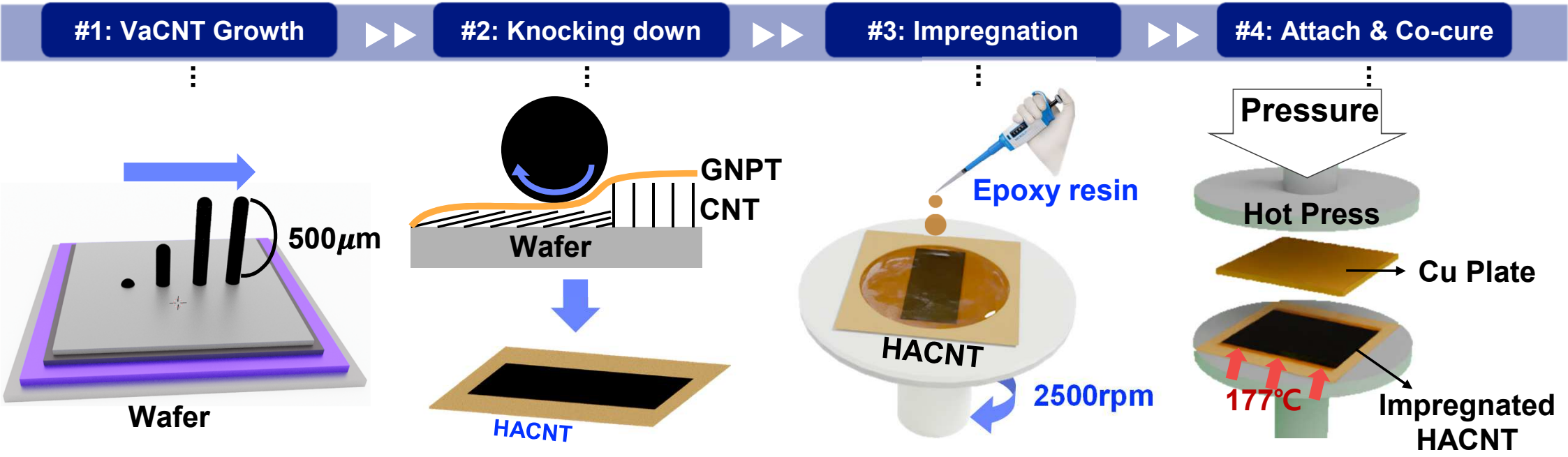


- **Spin Coater (G3P-8, SCS, USA)**
  - Ramp (10s)
  - Spin 2500 rpm (20s)
- **Impregnation**
  - Epoxy (Epon 862, Hexion, USA)
  - Hardener (EPIKURE w, Hexion, USA)
  - Solvent casting (Acetone)



- **Hot Press**
  - Carver (4120, Carver, USA)
- **Experimental condition**
  - 50 MPa
  - Cure - 177°C, 1 hours
  - Post cure - 177°C, 1 hours

2. Fabrication Process



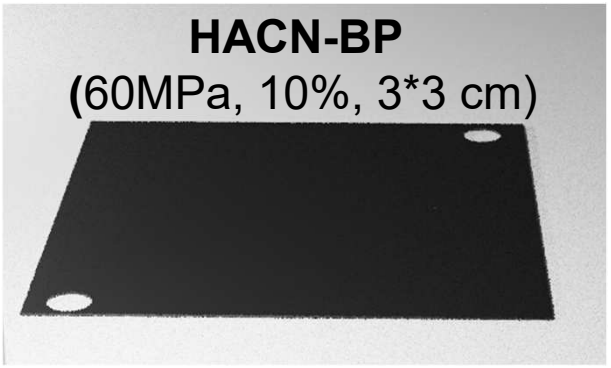
- **Parametric study** (# of specimens per group – 3)
  - Pressure: 15, 30, 45, 60 MPa
  - Dilution concentration: 10%, 15%, 20%, 25% per pressure

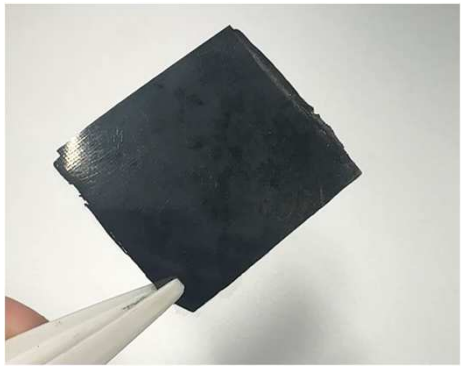
2. Experimental Results – Thickness measurements

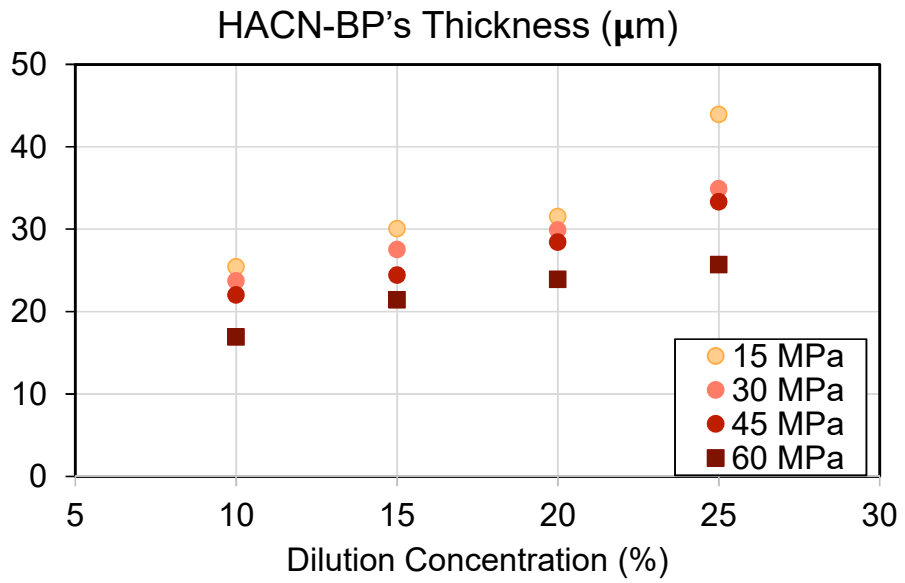
Thickness sensor

- **Measurement system**
  - Laser sensor (CL-L070, Keyence, USA)
- **Parametric study**
  - Applied Pressure (MPa): 15, 30, 45, 60
  - Dilution concentration (%): 10, 15, 20, 25

HACN-BP
(60MPa, 10%, 3*3 cm)

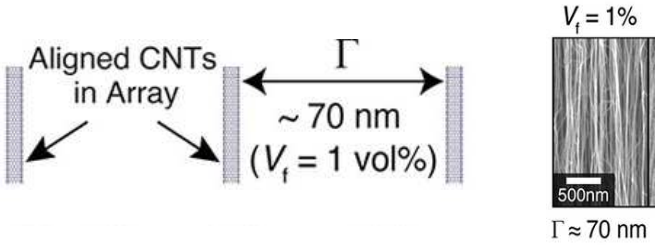






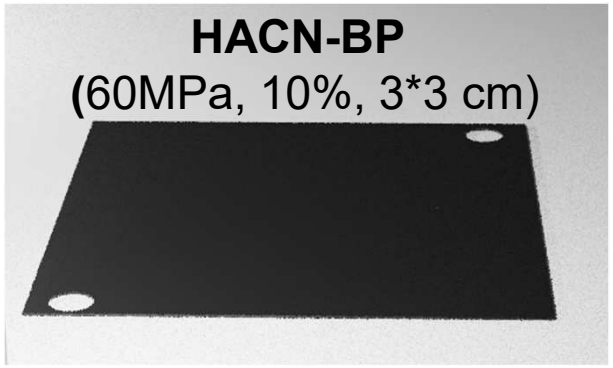
2. Experimental Results – CNT Volume Fraction

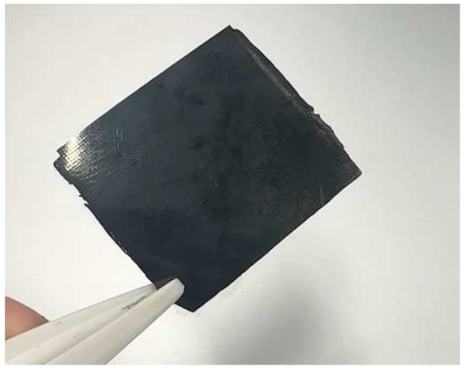
CNT Volume fraction

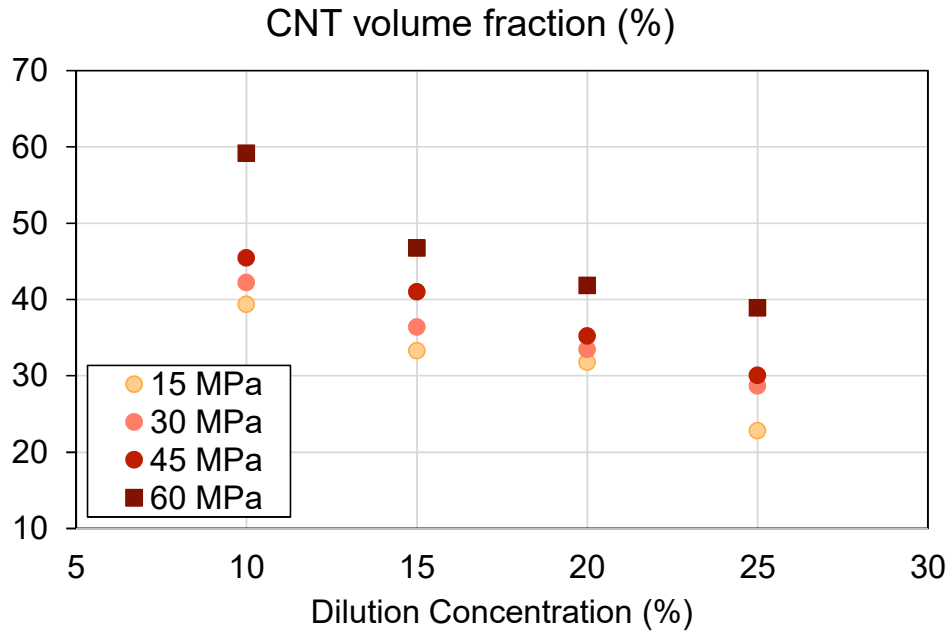


$$\text{CNT volume fraction} = \frac{\text{Initial CNT array height}}{\text{Final laminate height}}(\%) * 2 \text{ (plies)}$$

- **Parametric study**
  - Applied Pressure (MPa): 15, 30, 45, 60
  - Dilution concentration (%): 10, 15, 20, 25



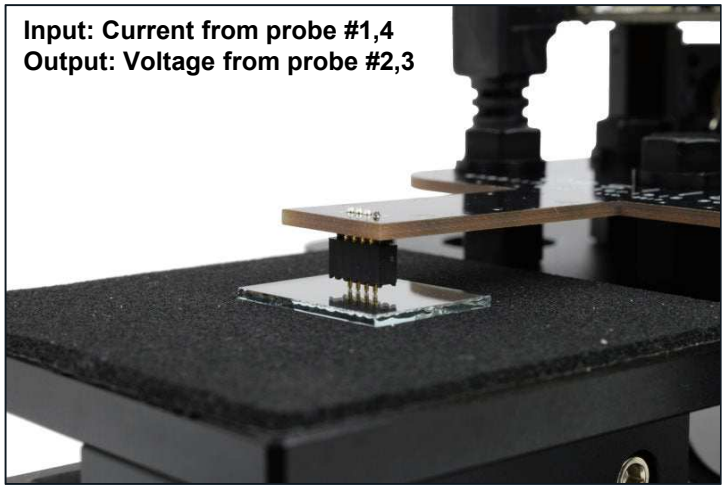




2. Experimental Results – ER* (In-plane dir.)

*ER - Electrical resistance

4-point probe method [1]

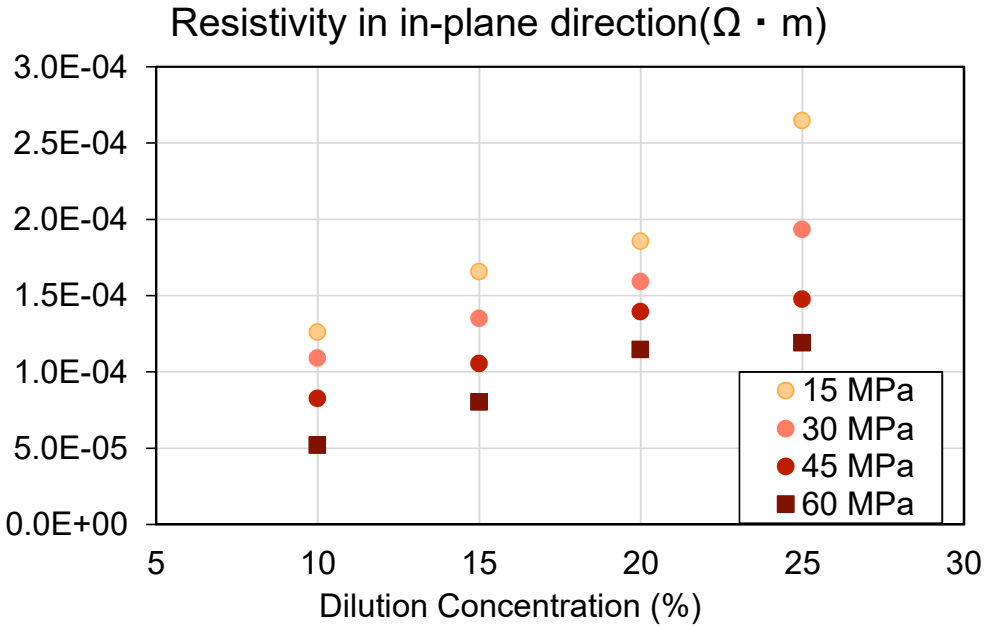


$$\rho(\text{resistivity}) = \frac{\pi}{\ln(2)} \times \frac{\Delta V}{I} \times \text{Thickness}$$

Correction factor

$$\sigma(\text{conductivity}) = \frac{1}{\rho}$$

Resistivity in in-plane direction (Ω·m)



- Conventional BP (In-Plane): $3 \cdot 10^{-3}$
- HACN-BP, BNL (In-Plane): $5 \cdot 10^{-5} \sim 3 \cdot 10^{-4}$

✓ Resistivity of HACN-BP 40 times lower.

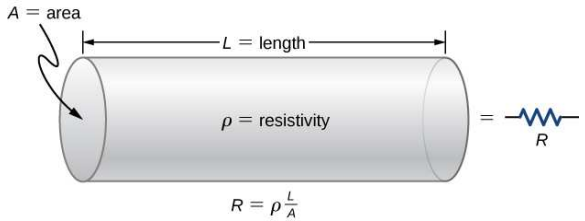
[1] Lee, Jeonyoon, et al. "Impact of carbon nanotube length on electron transport in aligned carbon nanotube networks." Applied Physics Letters 106.5 (2015): 053110.

2. Experimental Results – ER* (In-plane dir.)

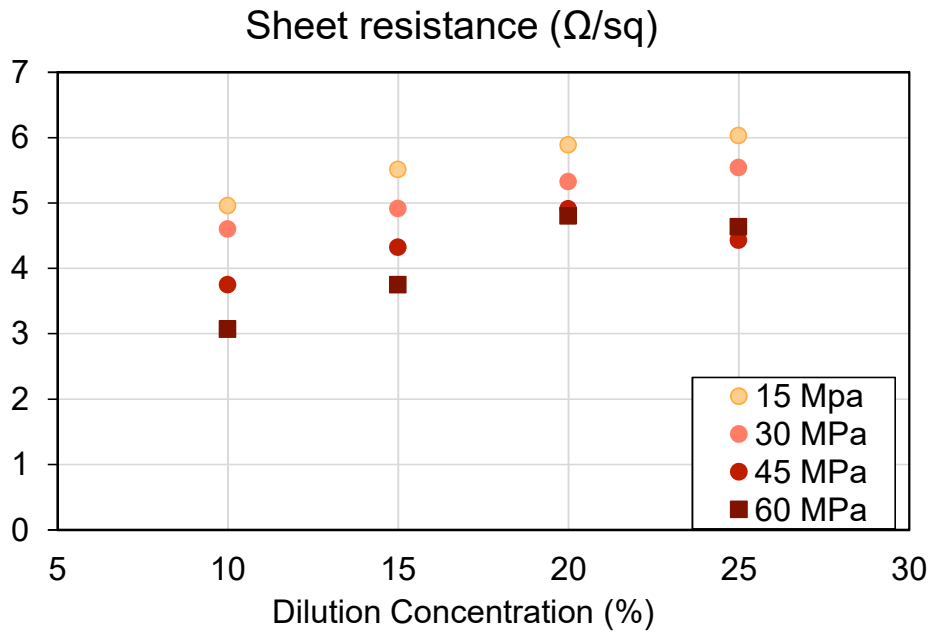
*ER - Electrical resistance

Sheet Resistance (Ω/sq)

$$\text{Sheet resistance}\left(\frac{\Omega}{\text{sq}}\right) = \frac{\rho(\text{resistivity})}{\text{thickness}}$$



The thinner the BP, the greater the electrical resistance.

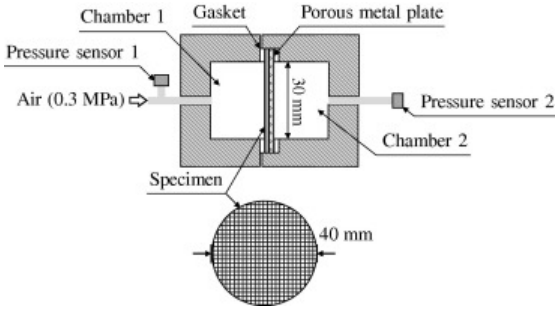


- Sheet resistance (Ω/sq)
  - BNL (In-Plane): 3.1 (10%, 60MPa)
  - Conventional BP (In-Plane): 4.7

- The thickness was reduced by 40 times, but the sheet resistance is still lower.
  - Energy density ↑ / Resistivity ↓

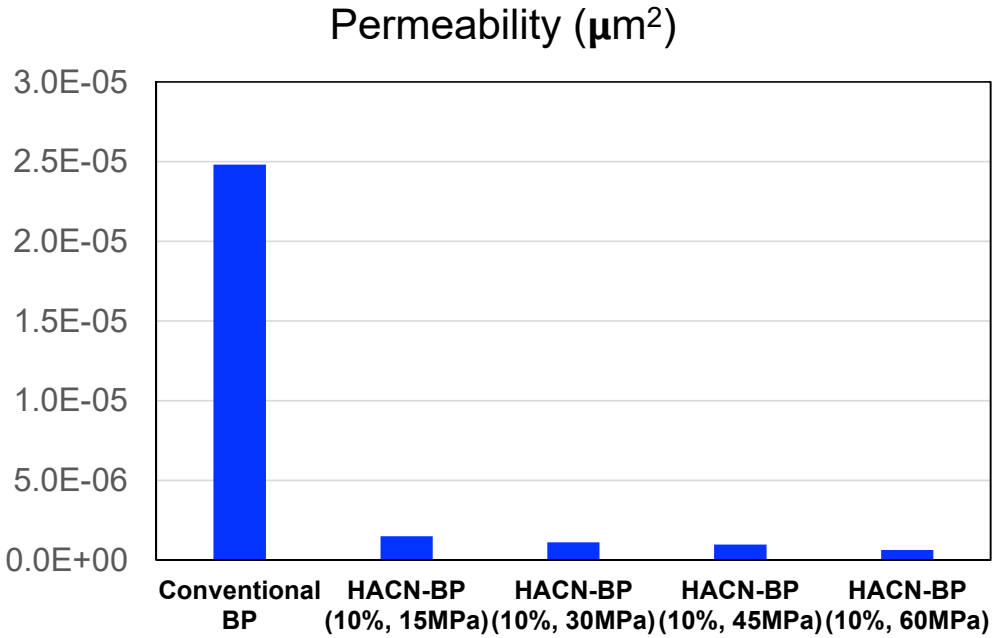
2. Experimental results – Permeability

Gas permeability (μm²)



POROLUX_1000

- Permeability (μm²)
  - HACN-BP (20μm): 3.1 (10%, 60MPa)
  - Conventional BP (700 μm): 4.7



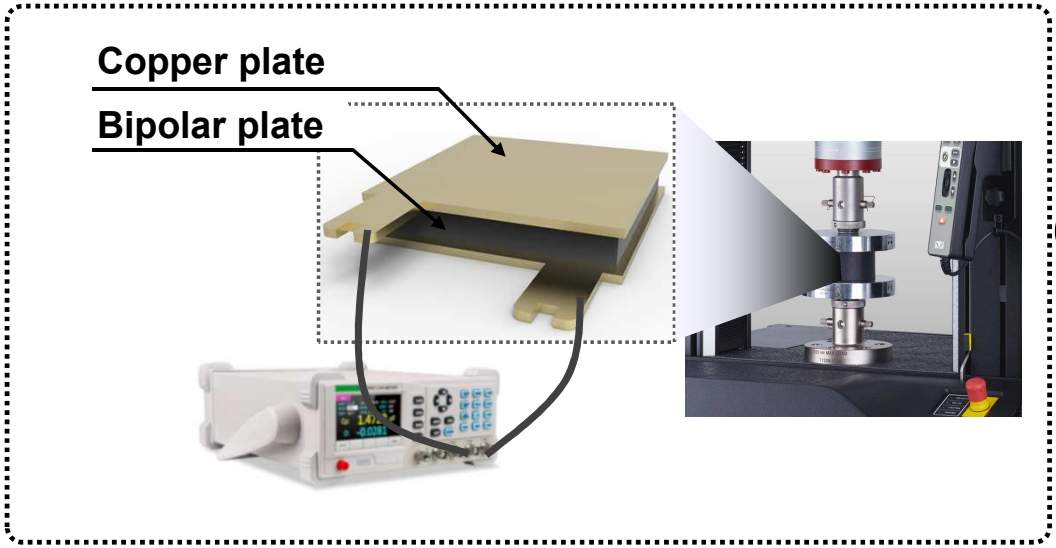
- Permeability is **38 times lower** in HACN-BP due to a high CNT volume fraction.

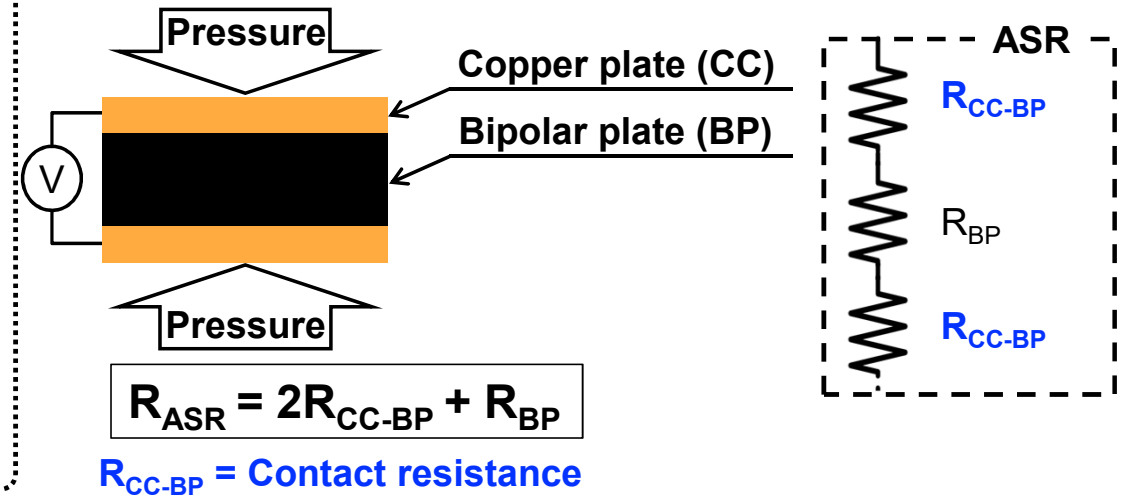
Knocked-down CNT (without polymer) → $8.7*10^{-4}$ μm²
Knocked-down CNT (with polymer) → $6.4*10^{-7}$ μm²

*ER - Electrical resistance

2. Experimental Results – ER* (Through thickness dir.)

Areal Specific Resistance (ASR)





$$R_{ASR} = 2R_{CC-BP} + R_{BP}$$

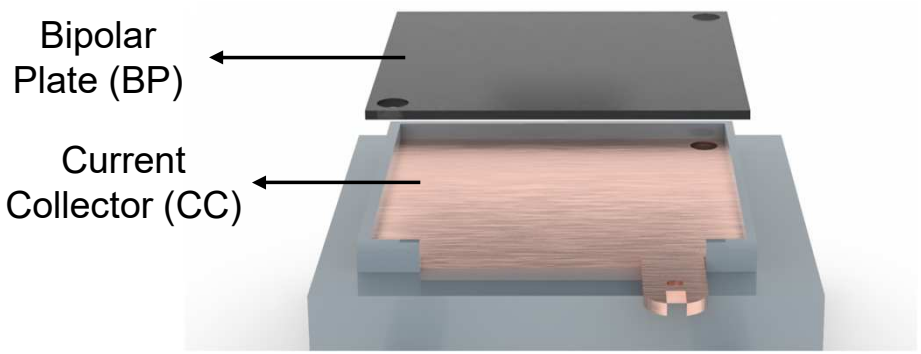
R_{CC-BP} = Contact resistance

- The VRFB is composed of various parts that are compressed by high pressure, which minimizes contact resistance.
  - ➢ VRFB requires consideration of ASR measurements.

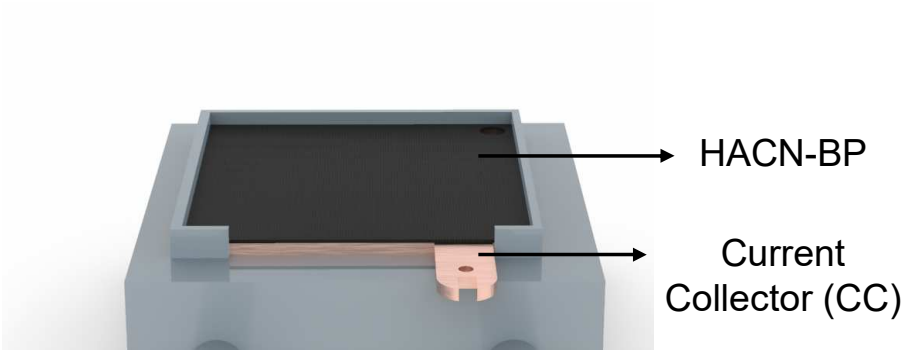
*ER - Electrical resistance

2. Experimental Results – ER* (Through thickness dir.)

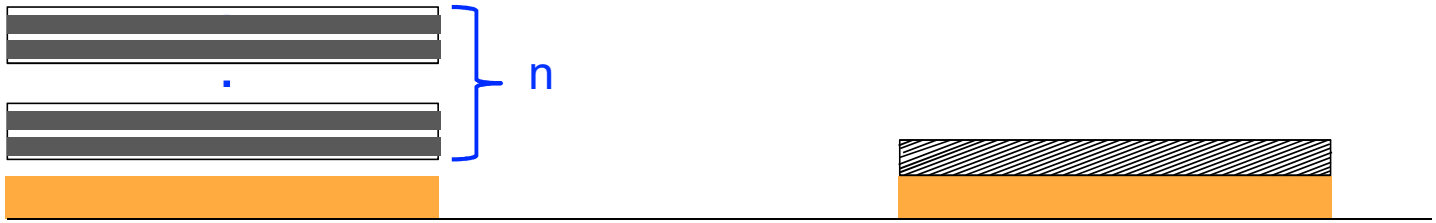
① **Conventional structures**
(BP and CC)

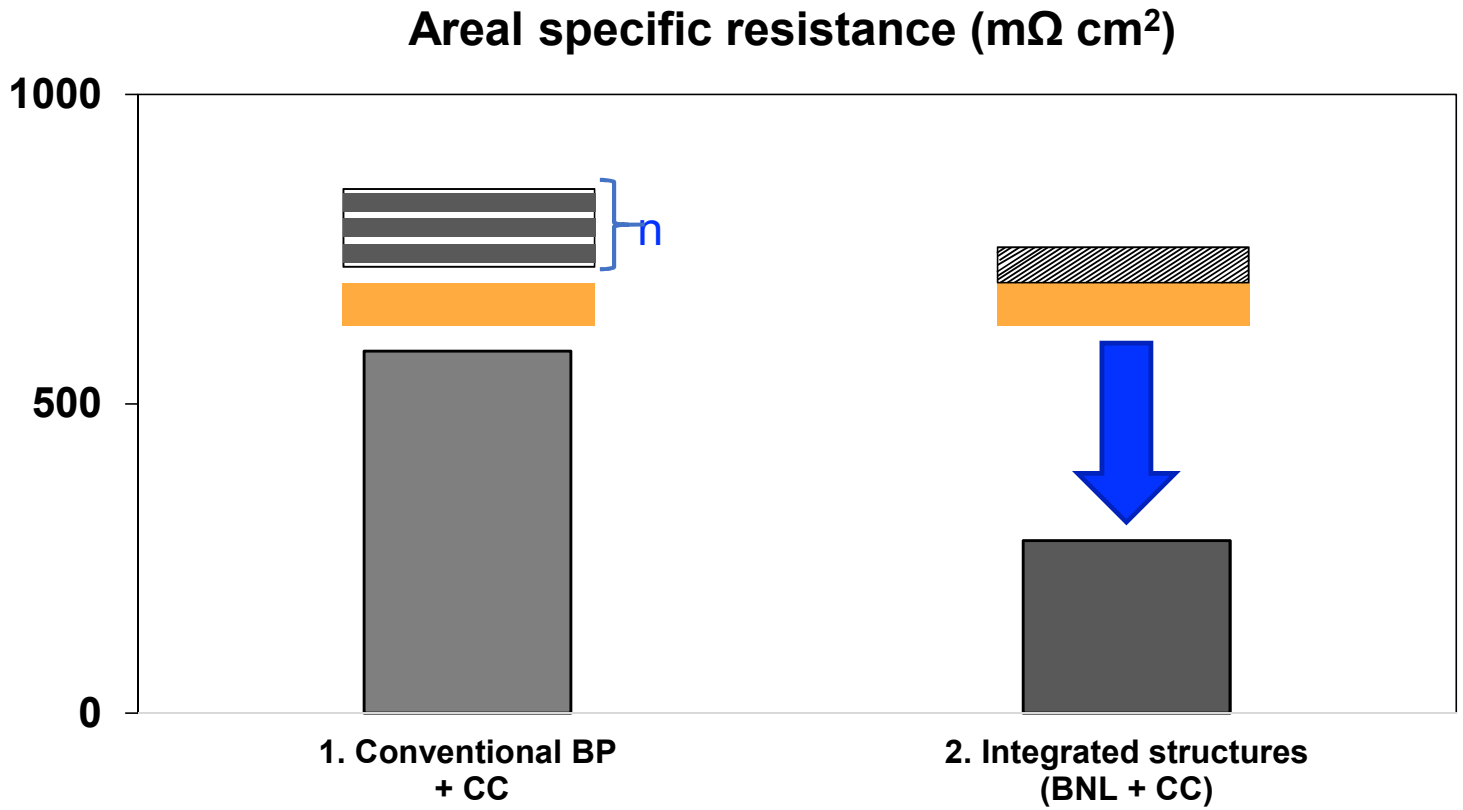


② **Integrated structures**
(HACN-BP + CC)



❖ **Cross-section**





- ER was lowered in ③ by eliminating contact resistance.
- As shown in ③, CNT aligned bottom to top lowers ER.

(Thickness = 1.1 cm) (Thickness = 1 cm)

3. Conclusion

- ✓ We propose that Horizontally Aligned CNT nanocomposite Bipolar plate (HACN-BP) reduces the electrical resistance by high CNT volume fraction and CNT well-aligned from bottom to top.
- ✓ HACN-BP also increases energy density due to being 40 times thinner yet showing lower permeability than conventional BP.
- ✓ The ability to attach HACN-BP to the current collector reduces contact resistance. This process is versatile and can be applied to the BP in various sizes of PEMFC or VRFB.

THANK YOU FOR YOUR ATTENTION!

MORE INFORMATION

[1] Kaiser, Ashley L., et al. "High-volume-fraction textured carbon nanotube–bis (maleimide) and− epoxy matrix polymer nanocomposites: Implications for high-performance structural composites." *ACS Applied Nano Materials* 5.7 (2022): 9008-9023.
[2] Jeong, Kwang Il, Seung A. Song, and Seong Su Kim. "Glucose-based carbon-coating layer on carbon felt electrodes of vanadium redox flow batteries." Composites Part B: Engineering 175 (2019): 107072.
[3] Qian, Hui, et al. "Activation of structural carbon fibres for potential applications in multifunctional structural supercapacitors." Journal of colloid and interface science 395 (2013): 241-248.