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High-Voltage Electrical Double-Layer Capacitors

Graphene Task Force
Project Manager

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Systems Research
Laboratories

Industrial Technology
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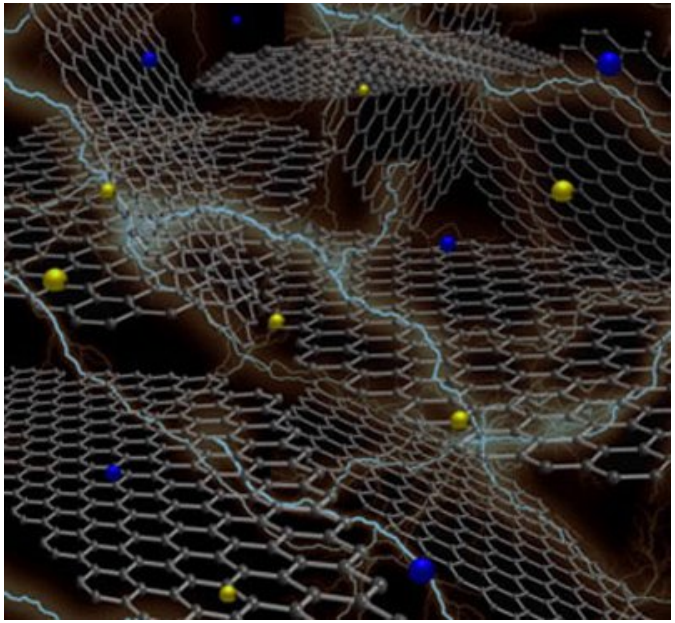
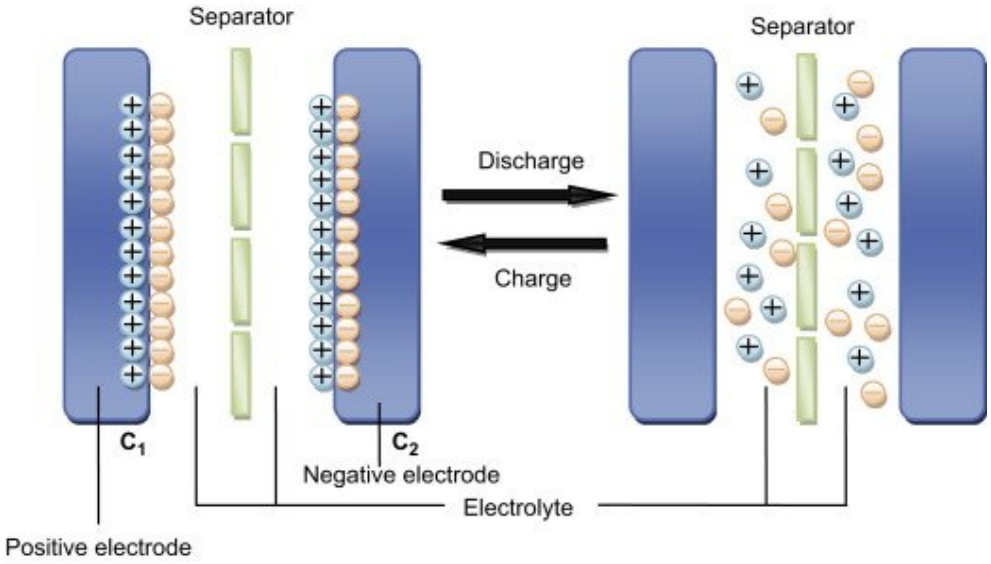
Graphene
Background

- High specific surface ratio (2630 m^2/g)
- High specific capacitor (530 F/g)
- High electron transport (200, 000 cm2·V−1·s−1)



http://physicsworld.com/cws/article/news/2012/mar/20/laser-writer-makes-graphene-supercapacitors



http://energyeducation.ca/encyclopedia/Supercapacitor

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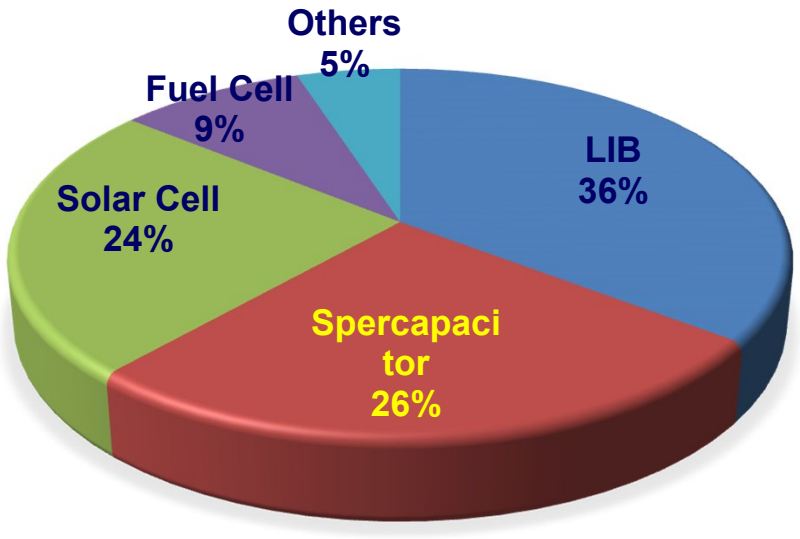
Graphene
Patent Analysis of Energy Storage

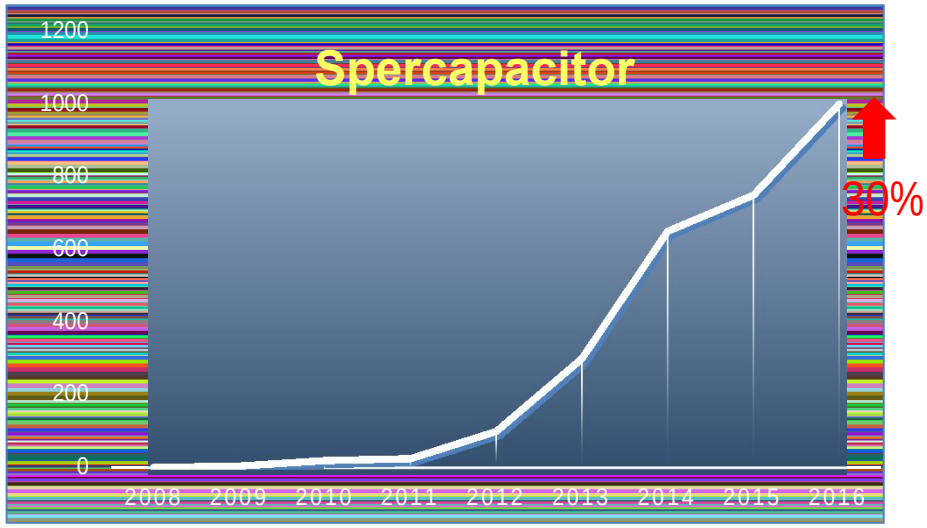
- Graphene supercapacitor can provide high power density (>2k W/h)
- Supercapacitor has longer cycle life (>10, 000 cycles)

Energy Storage Patent Analysis



11,852 patents

Trend Chart of Supercapacitor Patent



30% annual growth

K. P. Huang

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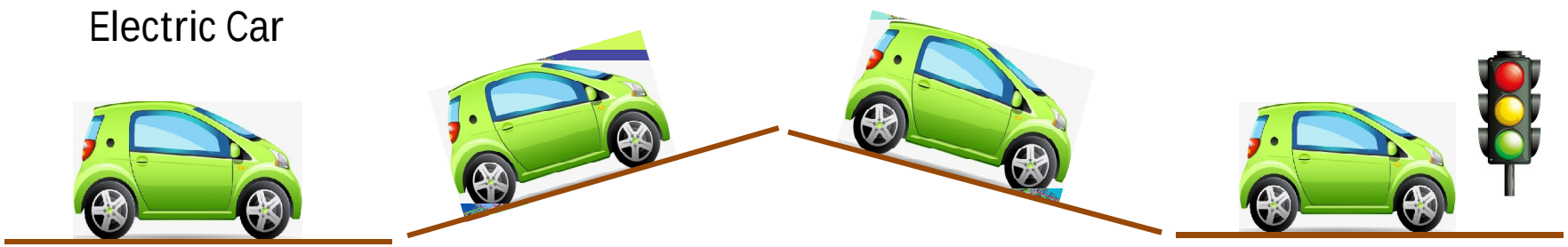
Graphene
LIB and Spercapacitor



Working Voltage ~2.8V

Volume ?

http://www.ecmag.com/section/your-business/tesla-gives-ev-battery-industry-jolt

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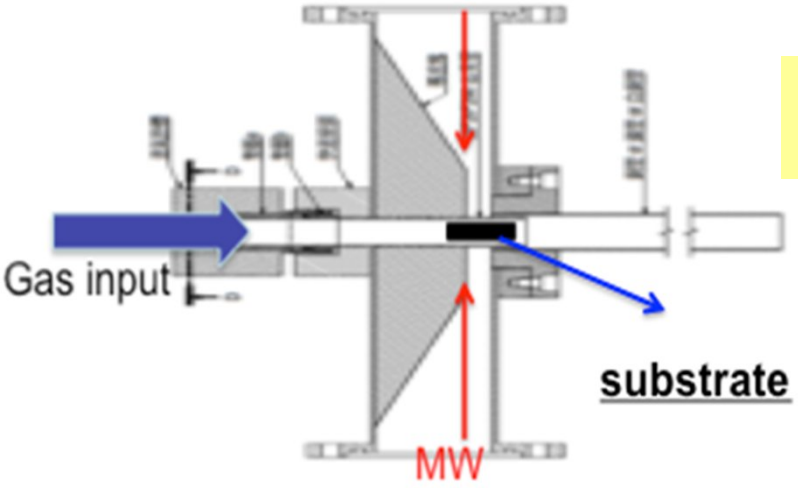
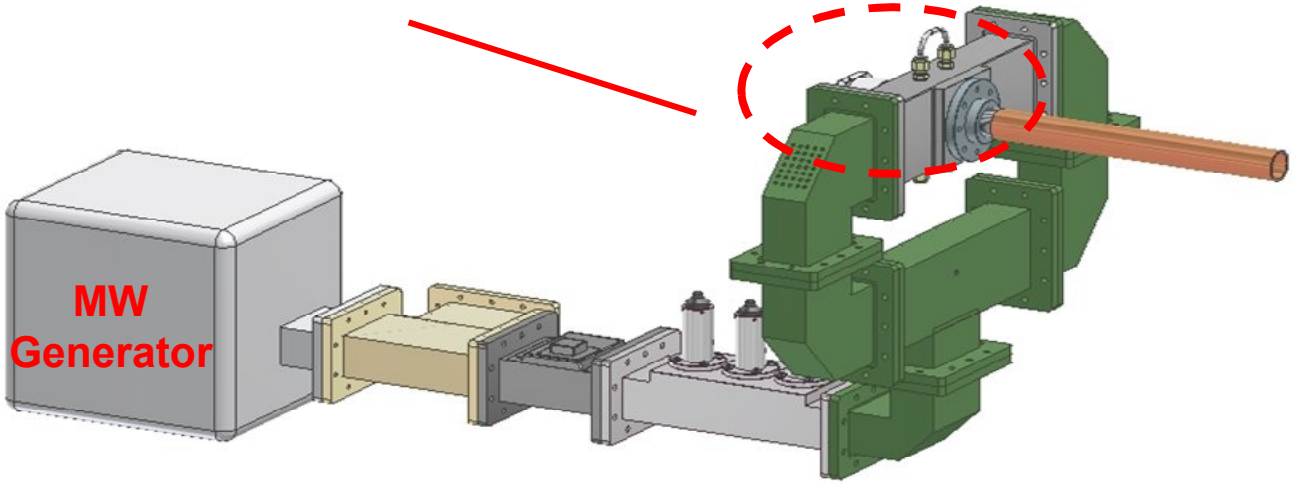
MP CVD
Bottom-Up Synthesis

Ar
CH_4
N_2



Ionization > 40%
Plasma Density > 1E14 ion/cm^3

Reaction Area



Microwave Plasma enhanced Chemical Vapor Deposition

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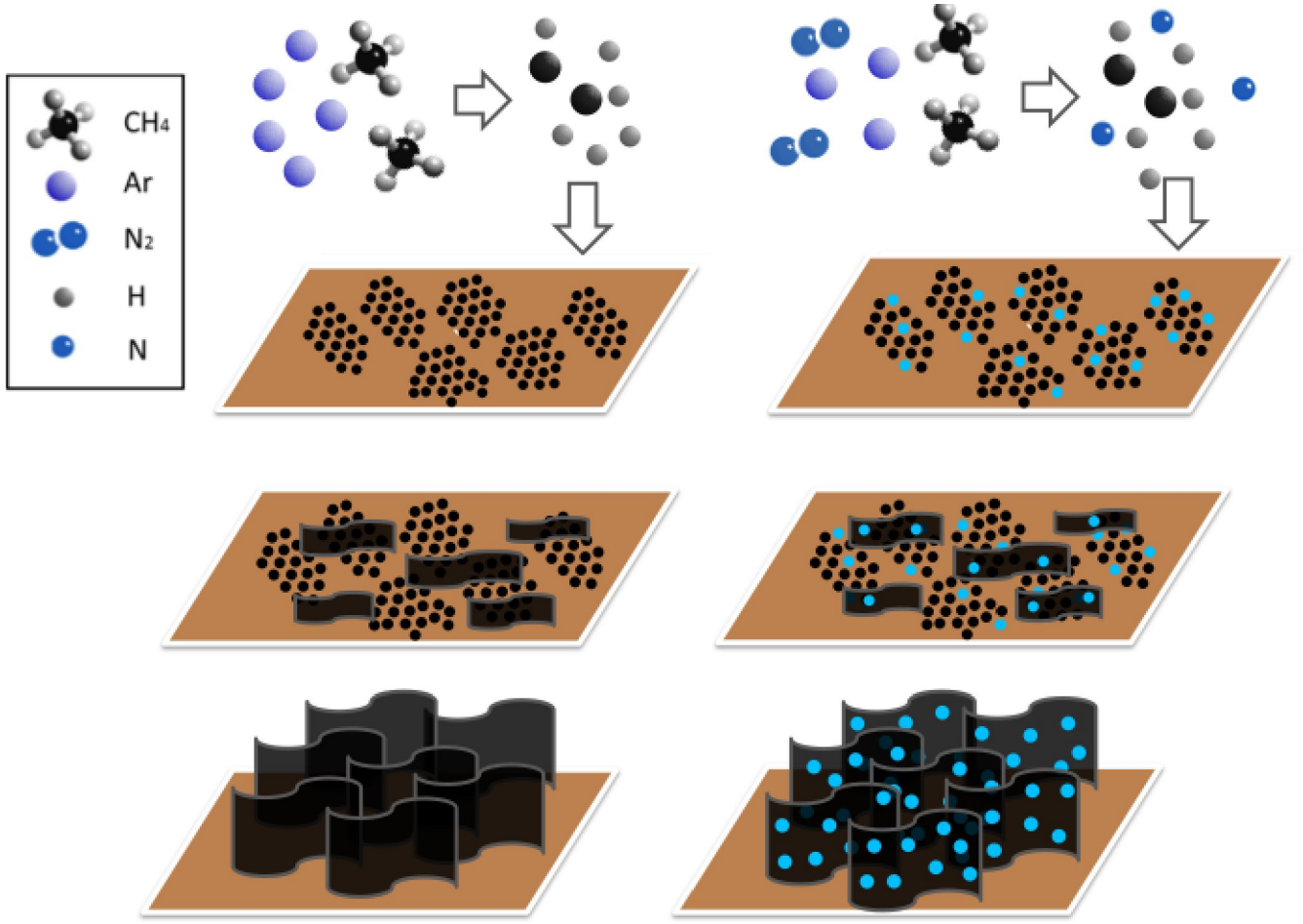
Graphene Nanowalls
Growth and Doping

NGNW growth through Plasma



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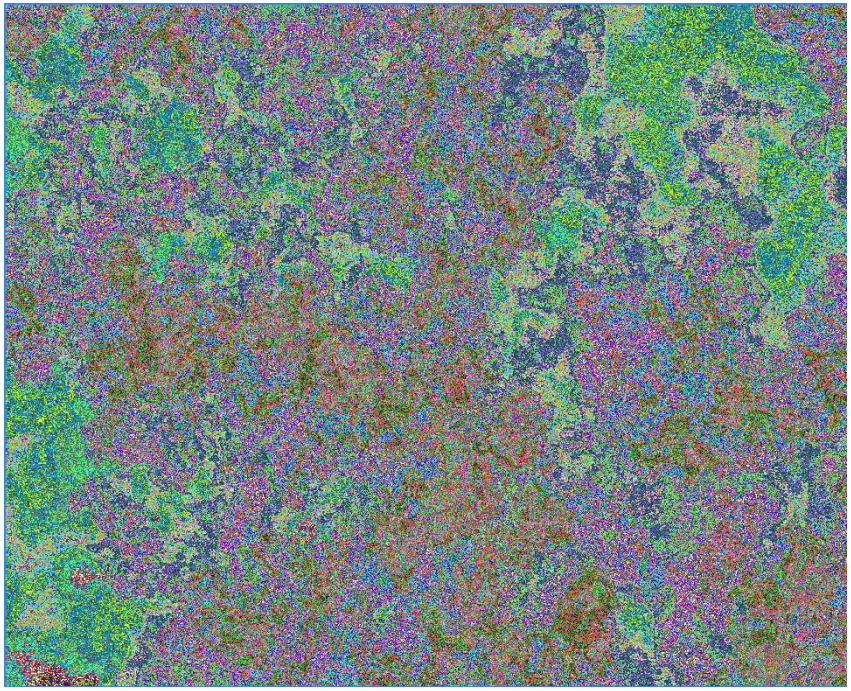
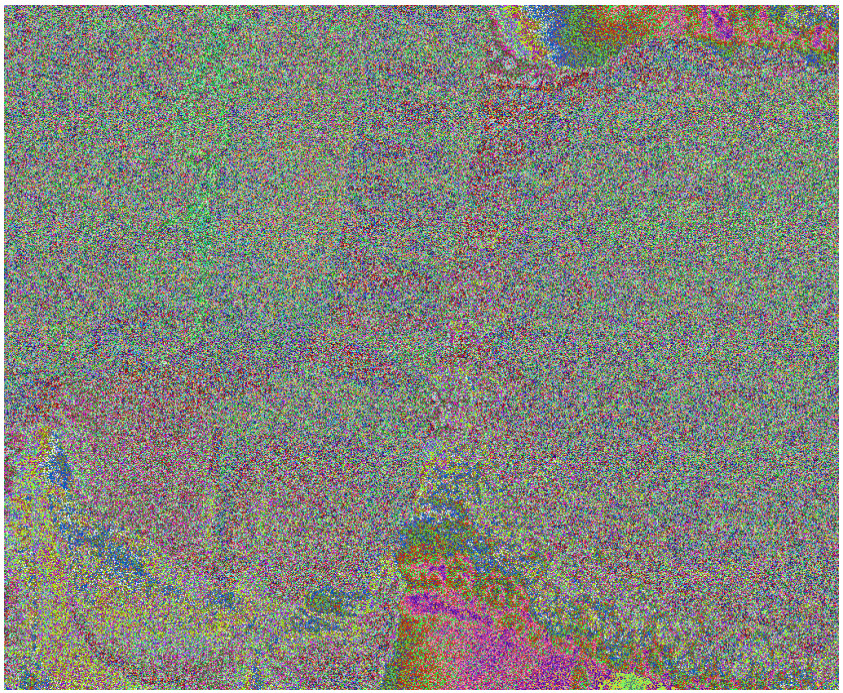
Bottom-Up Synthesis
Graphene Allotrope

> 100 torr



Graphene Powder

< 100 torr



Graphene Nanowall

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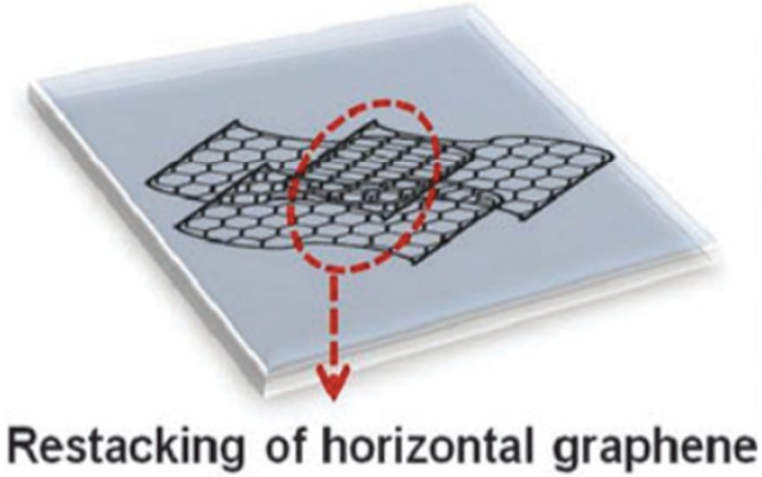
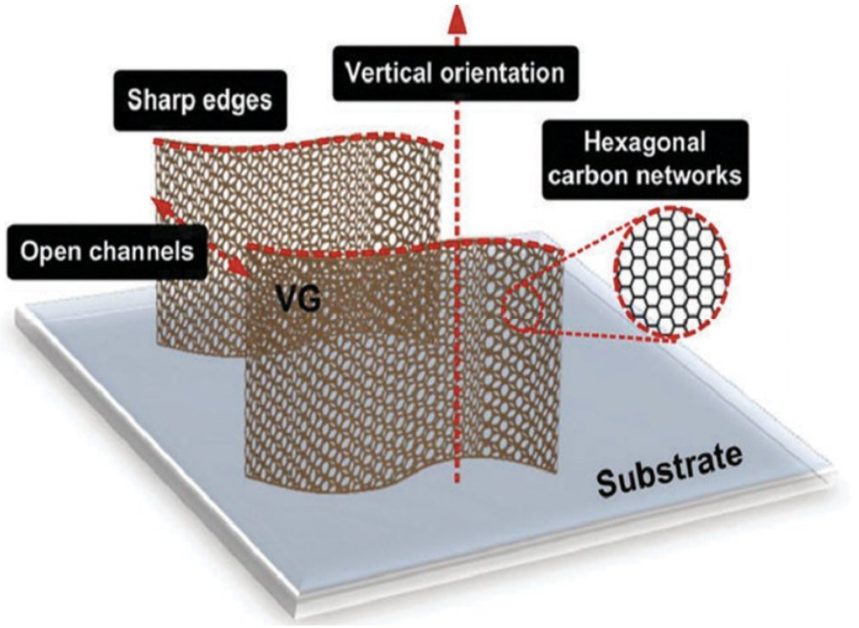
Supercapacitor
Powder vs GNW





Chen, J., Bo, Z., & Lu, G. (2015). Vertically-Oriented Graphene. Springer International Publishing Switzerland, DOI, 10, 978-3.

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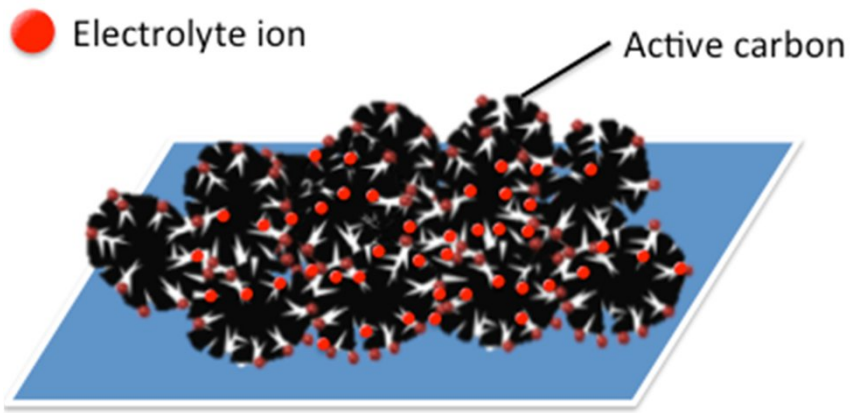
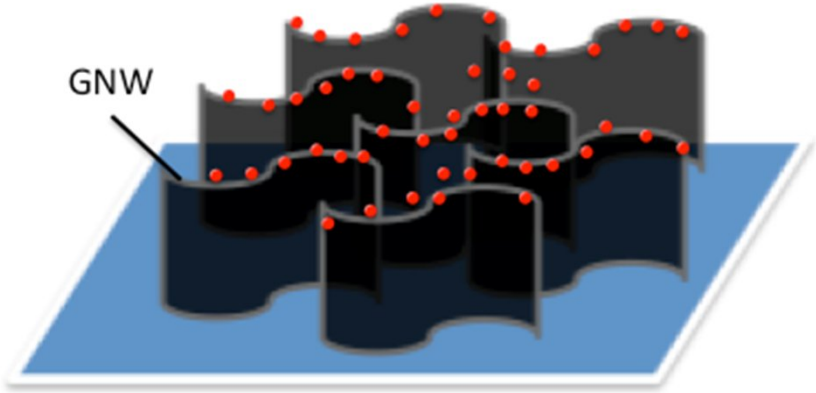
Supercapacitor
Powder vs GNW





Graphene powder with a lot reactive edge and random distribution. The reaction (oxidation or HER) is easy happen between the electrolyte and active material.
➔ Cell voltage can't higher than 2.8V.

GNW with few edge and regular distribution and it provide these inner face between active material and electrolyte.
➔ without oxidation reaction or HER.
➔ Cell voltage raise to 4V.

Naoi, K. (2010). 'Nanohybrid capacitor': the next generation electrochemical capacitors. Fuel cells, 10(5), 825-833.

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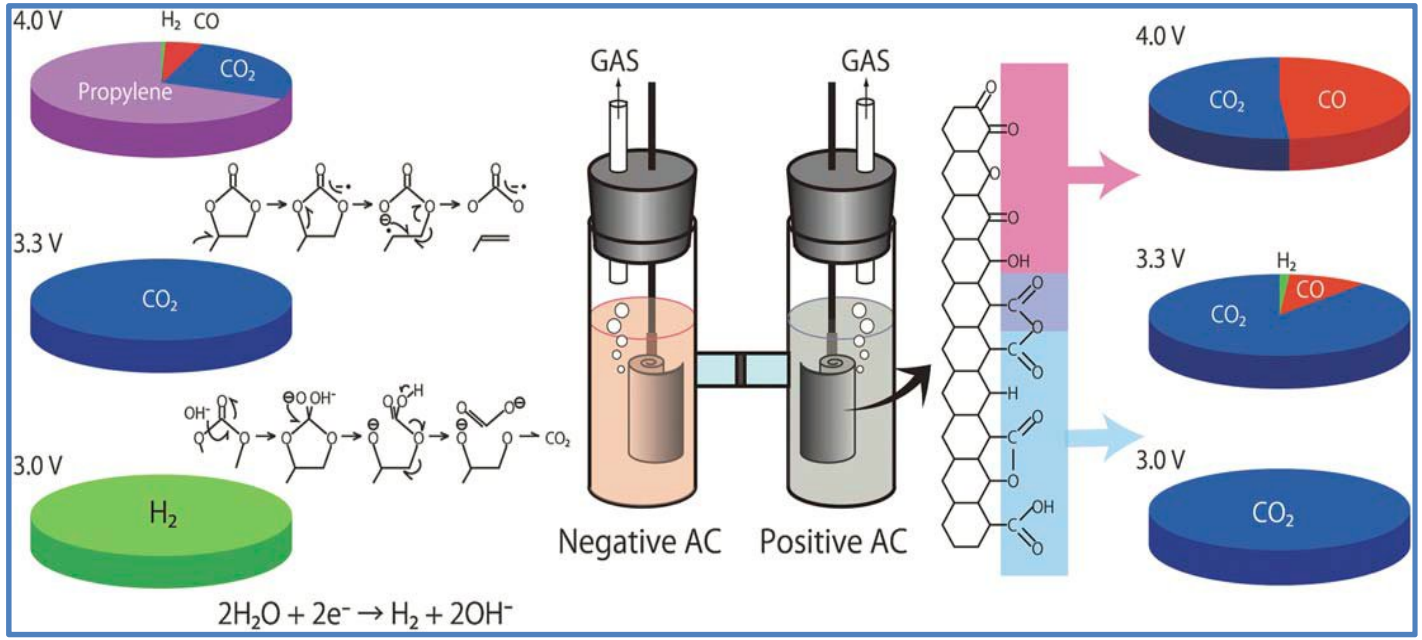
Supercapacitor
Edge Reaction

Reduce the electrode activity to electrolyte/the interface reactions



Gas evolution from an EDLC cell upon over-voltage application.

Naoi, K. (2010). 'Nanohybrid capacitor': the next generation electrochemical capacitors. Fuel cells, 10(5), 825-833.

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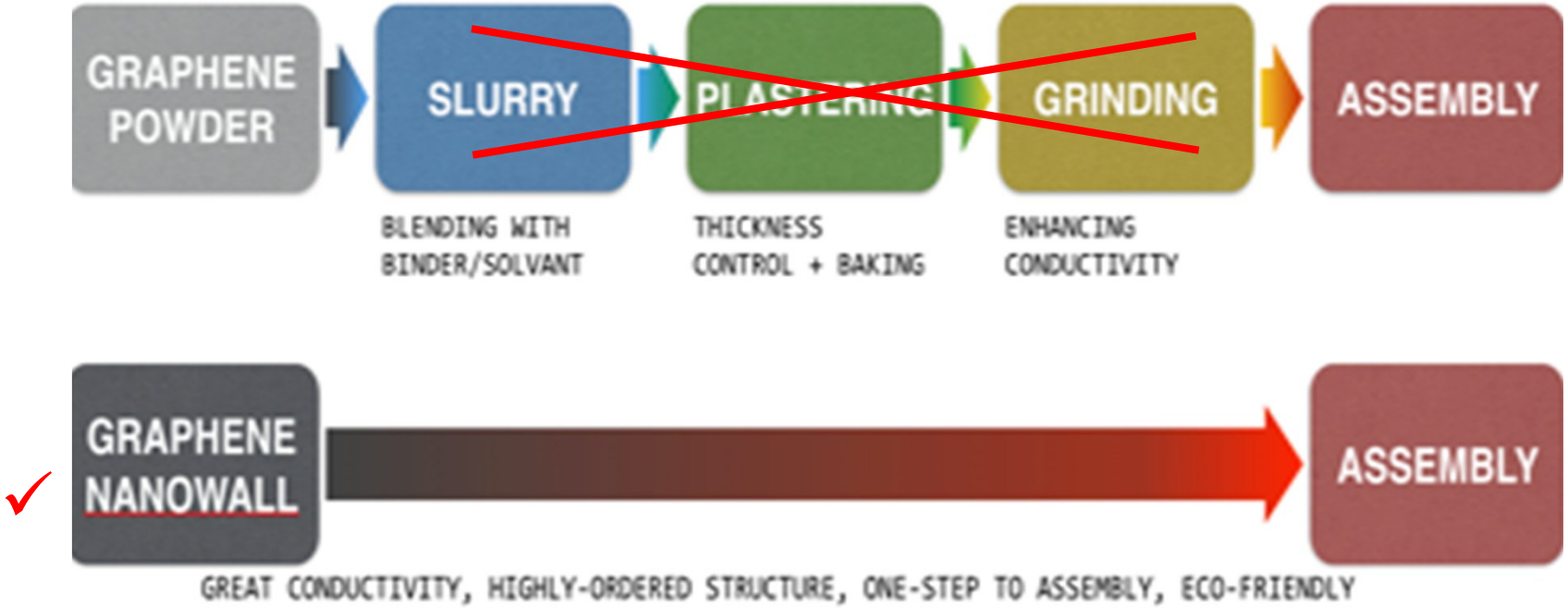
Supercapacitor
Powder vs GNW



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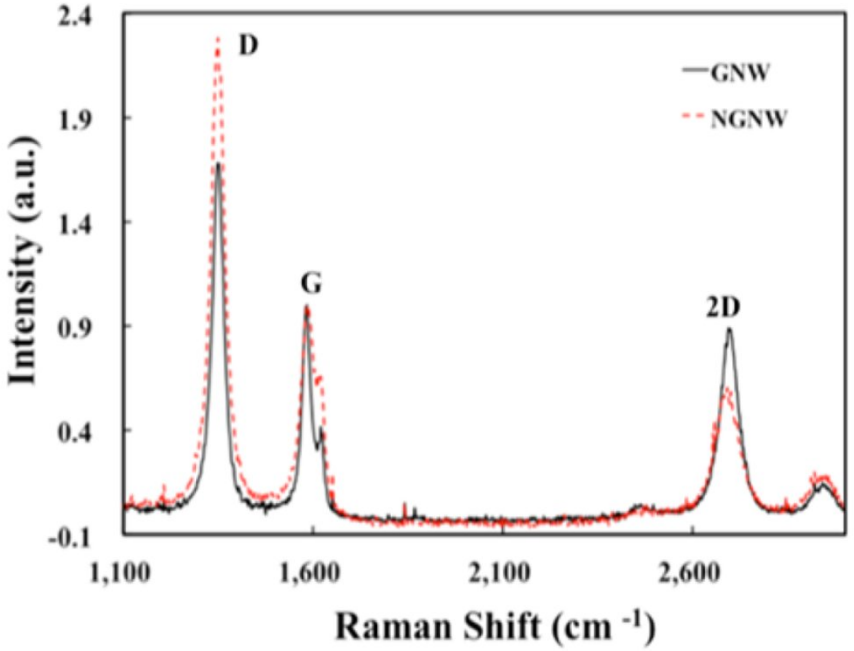
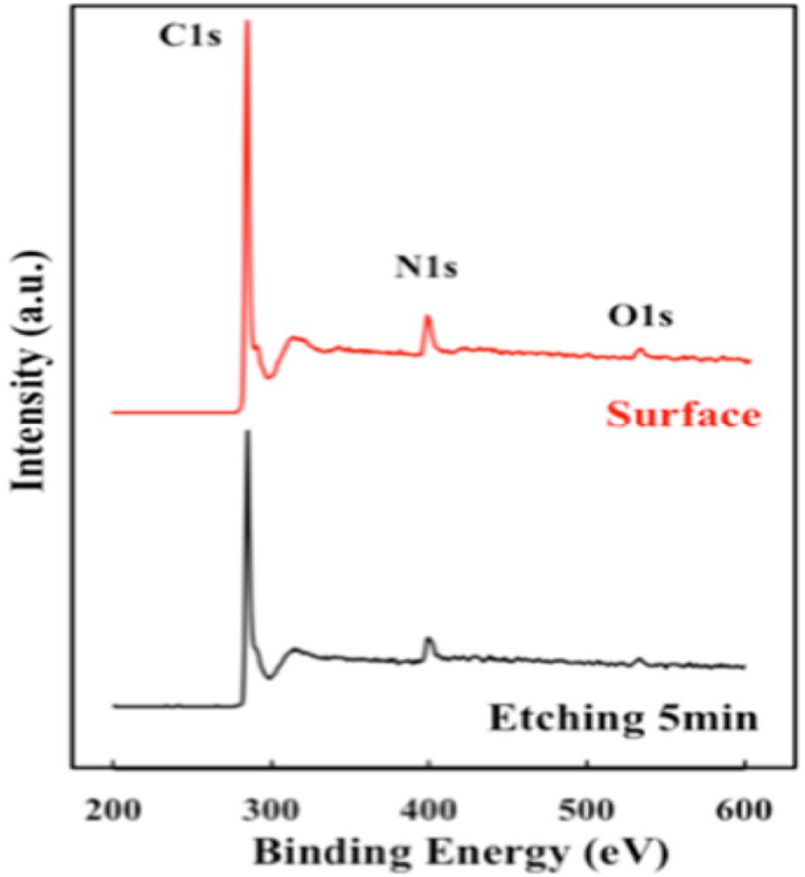
Graphene Nanowalls
Chemical Analysis

Raman



Nano Lett. 2016, 16, 5719−5727

XPS



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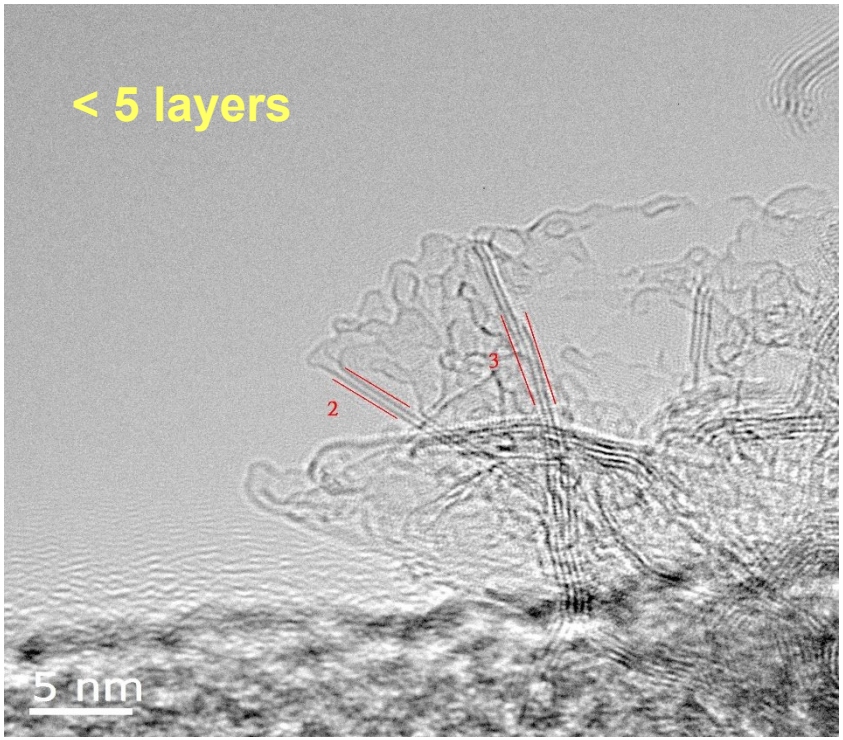
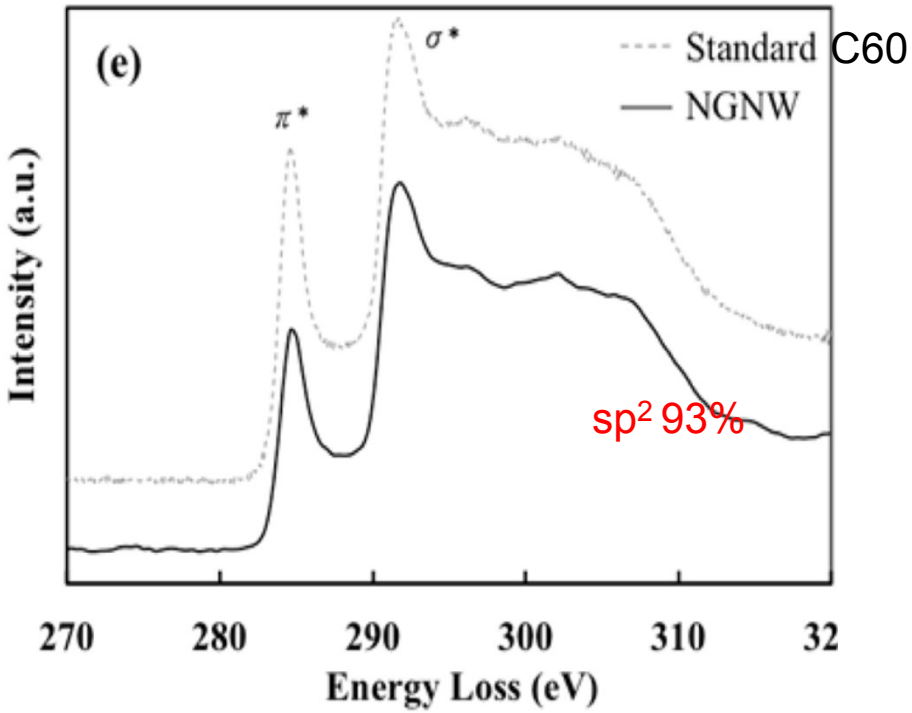
Graphene Nanowalls
LP HRTEM

TEM



EELS



Nano Lett. 2016, 16, 5719−5727

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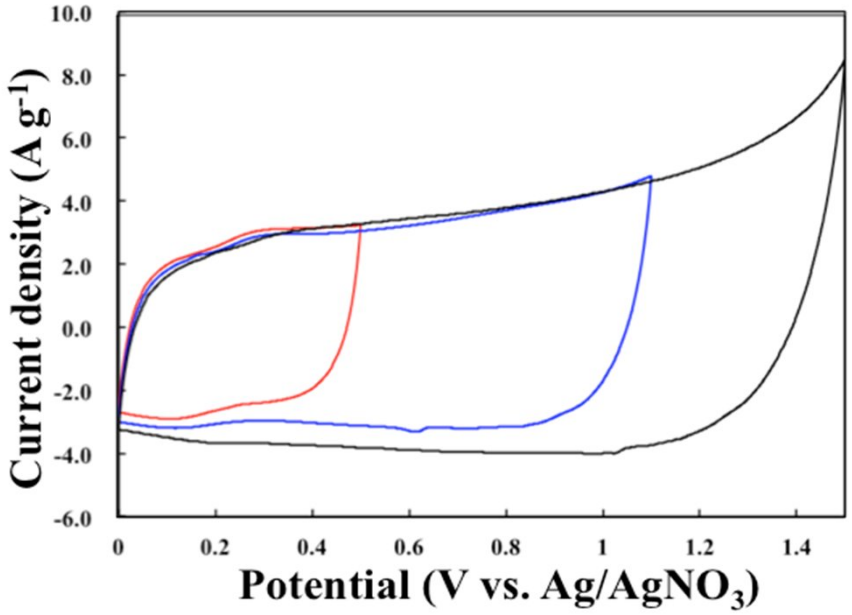
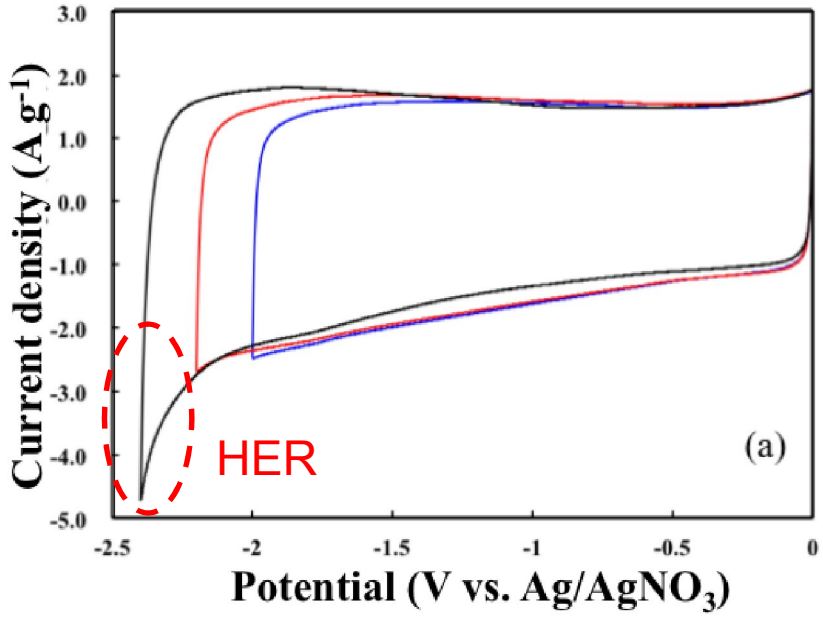
Supercapacitor
GNW

Positive



Negative



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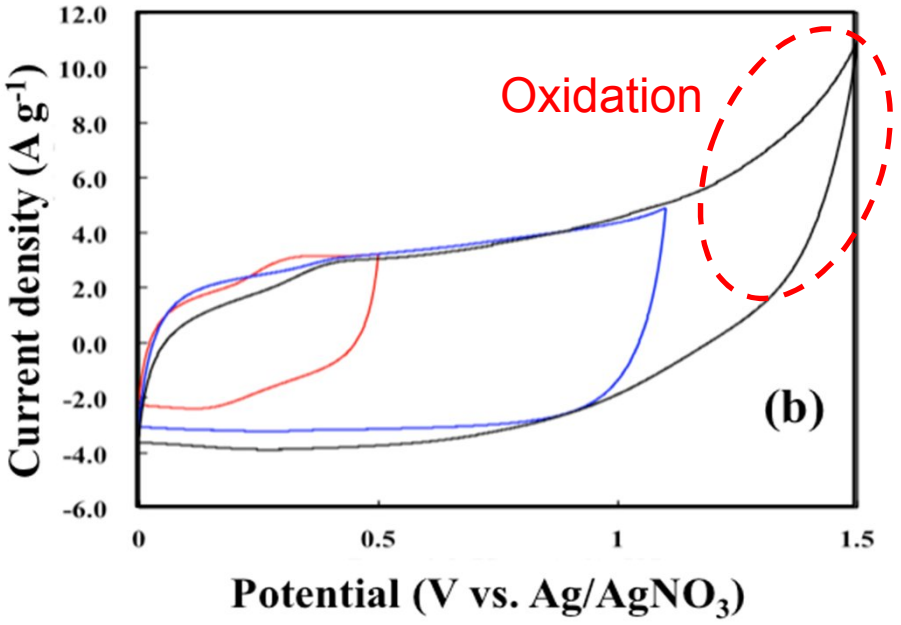
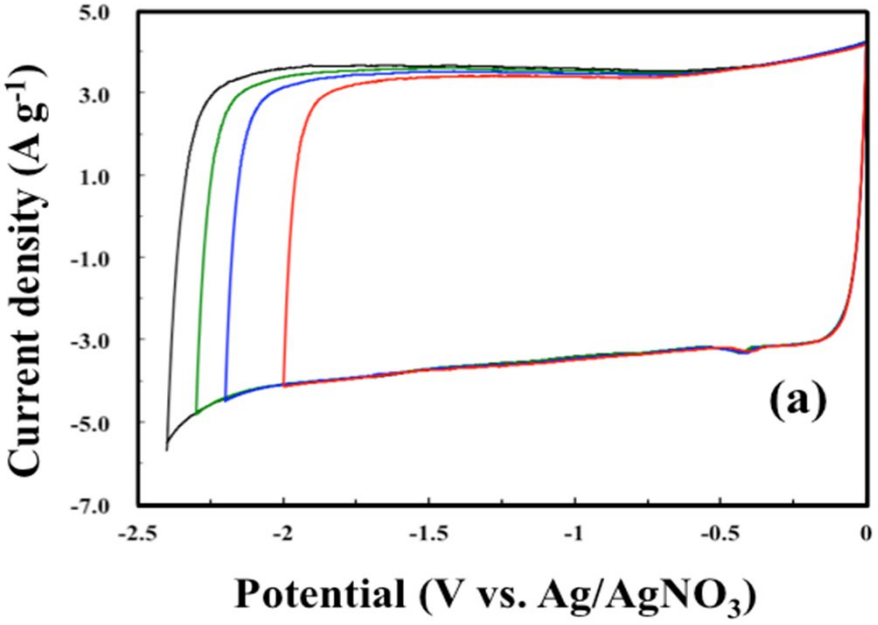
Supercapacitor
NGNW

Positive



Negative



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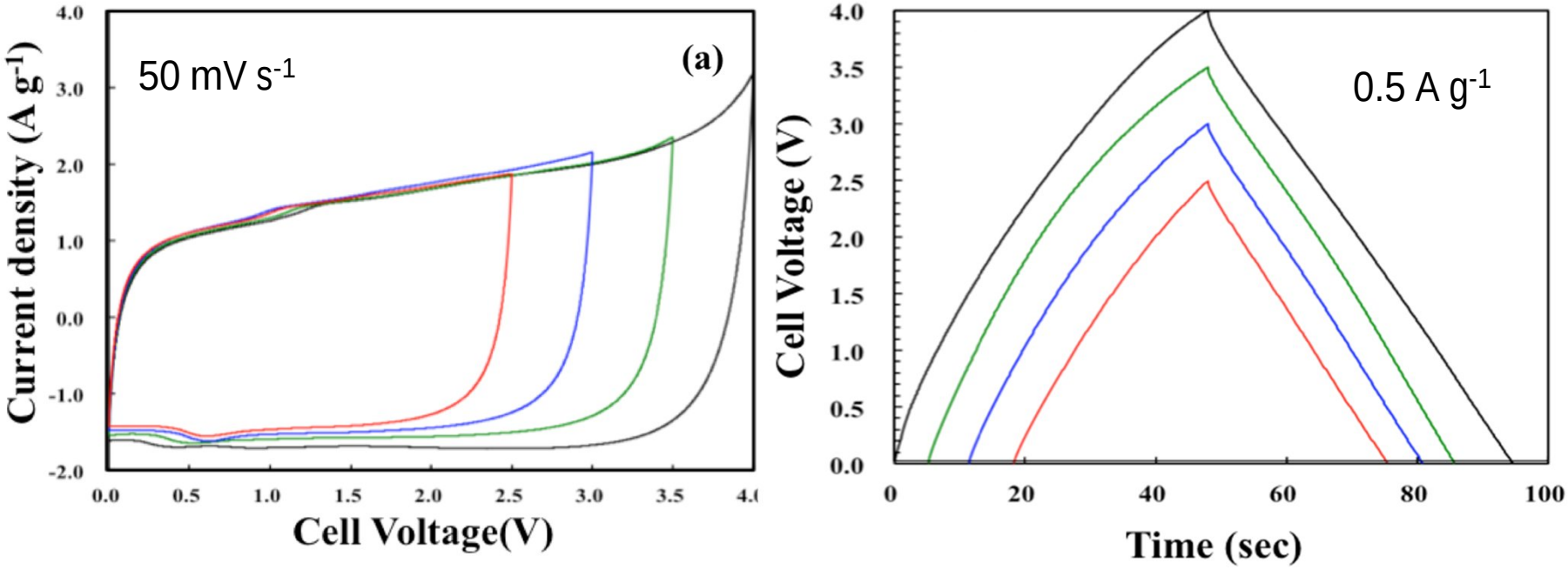
Supercapacitor
GNW-NGNW



(a) CV curves and (b) constant-*i* charge-discharge curves of an N-graphene //LQ graphene ASC in 1 M $TEABF_4$/PC with a cell voltage of 2.5, 3.0, 3.5, 4.0 V at 50 mV/s or 2 A/g.

N-graphene (-)//GNW (+) is a 4V EDLC

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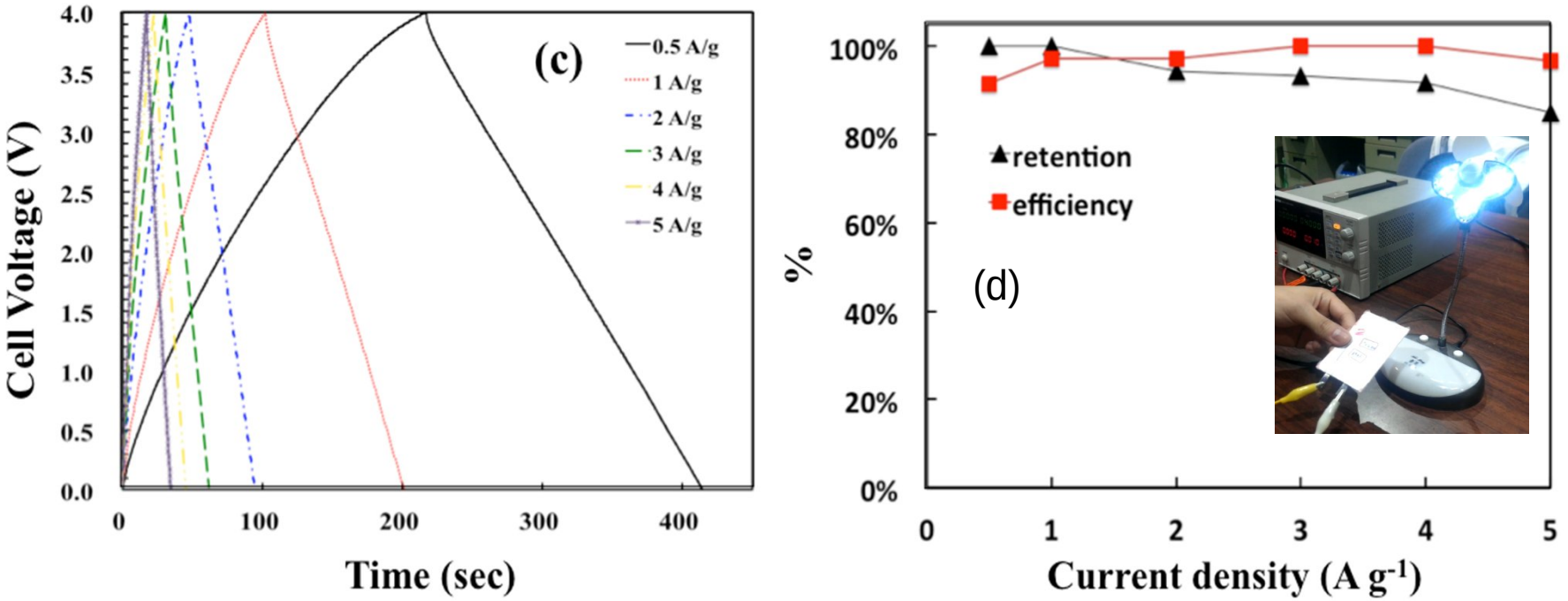
Supercapacitor
GNW-NGNW



(c) The charge-discharge curves of an N-GNW (-)//GNW (+) ASC in 1 M $TEABF_4$/PC with a cell voltage of 4.0 V at 0.3, 0.5, 1, 2, 3, and 5 A/g. (d) The C.E. and cell capacitance retention vs. charge-discharge current density for symmetric and asymmetric designs.

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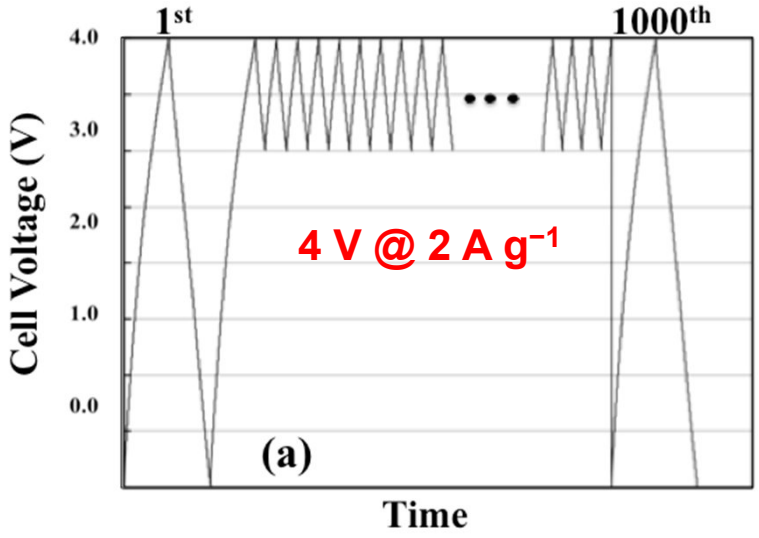
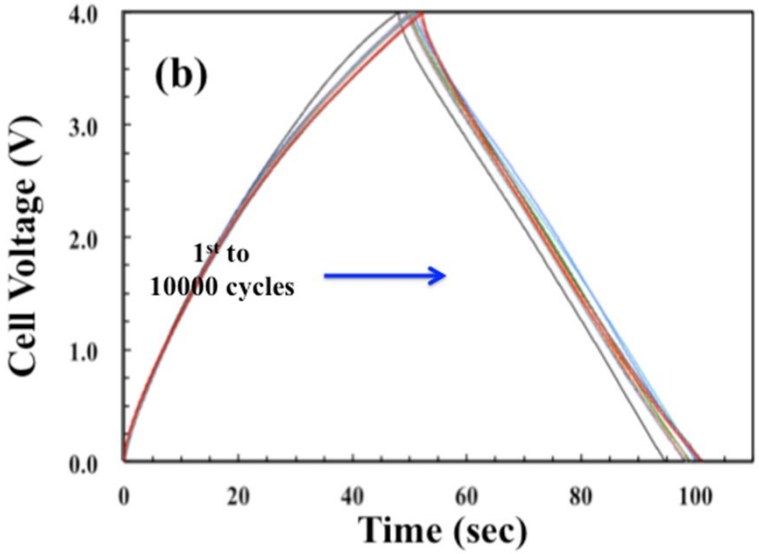
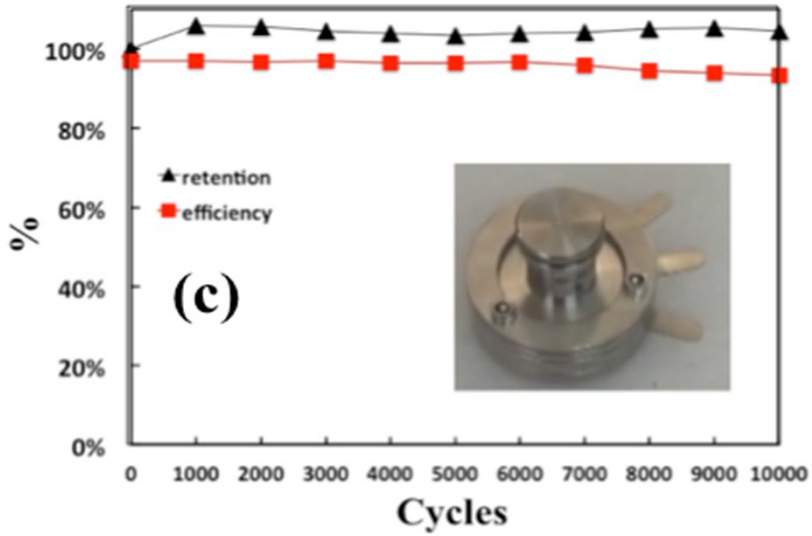
Supercapacitor
Cycle Life Test







After 10000 cycles, efficiency and retention are still maintain 93% and 100% respectively.

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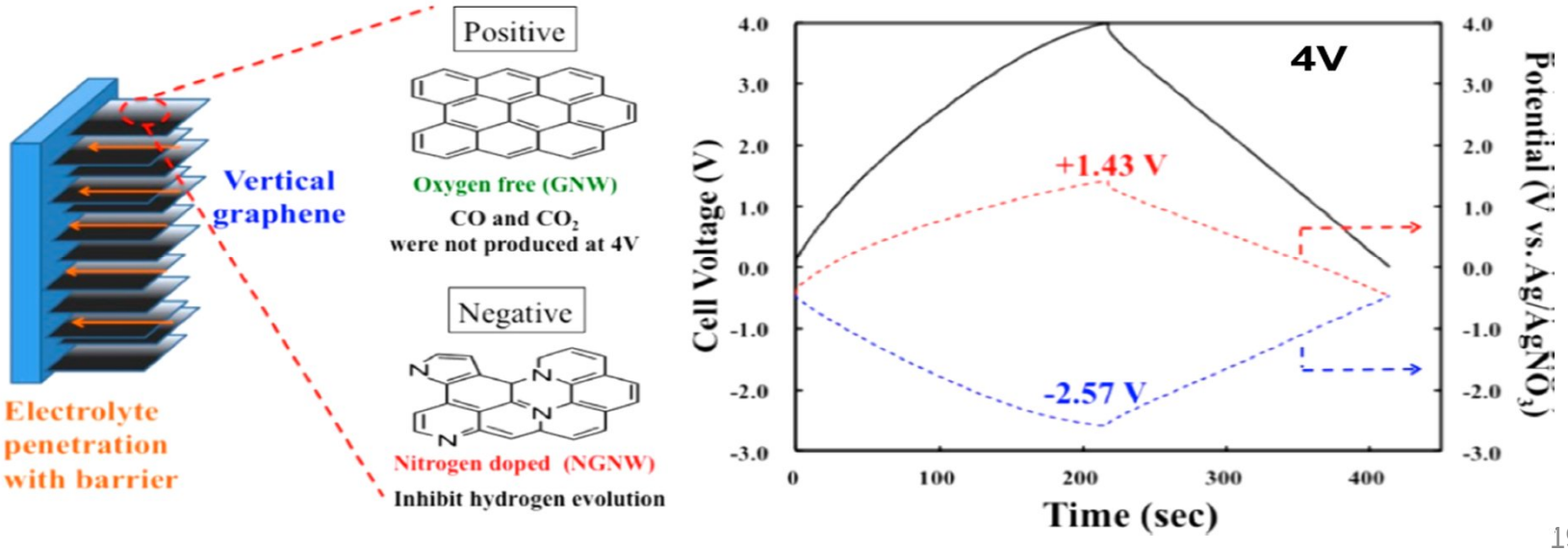
Conclusions

- MP CVD can grow and dope graphene at the same time.
- GNW ➔ Oxygen free ➔ inhibit oxidation reaction ➔ Be positive electrode 1.43V
- NGNW ➔nitrogen inhibit HER reaction ➔ Be negative electrode -2.57V
- Asymmetric electrodes can accomplish 4V electrical double-layer capacitors. (Energy Density is 53 Wh/kg; Power Density is 8k W/kg)



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Acknowledgements

Funding

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Collaboration

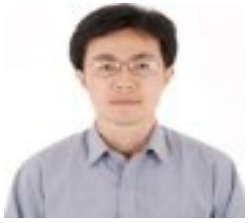
Graphene Task Force

Consultant

Prof. C. S. Kou

Prof. C. C. Hu

Team Members



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Miss Y. W. Chi

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Mr. J. C. Ho

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Thanks for your attention!

黃昆平