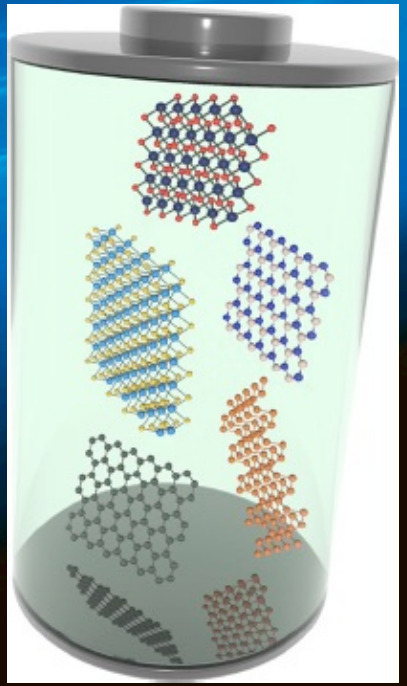
How Can 2D Materials Advance Energy Storage ?

15th Anniversary High Value Manufacturing & 4th New Materials & Graphene Conference 2017
2-3 November 2017
www.cir-strategy.com/events



Dr M. J. Loveridge, **Warwick University**

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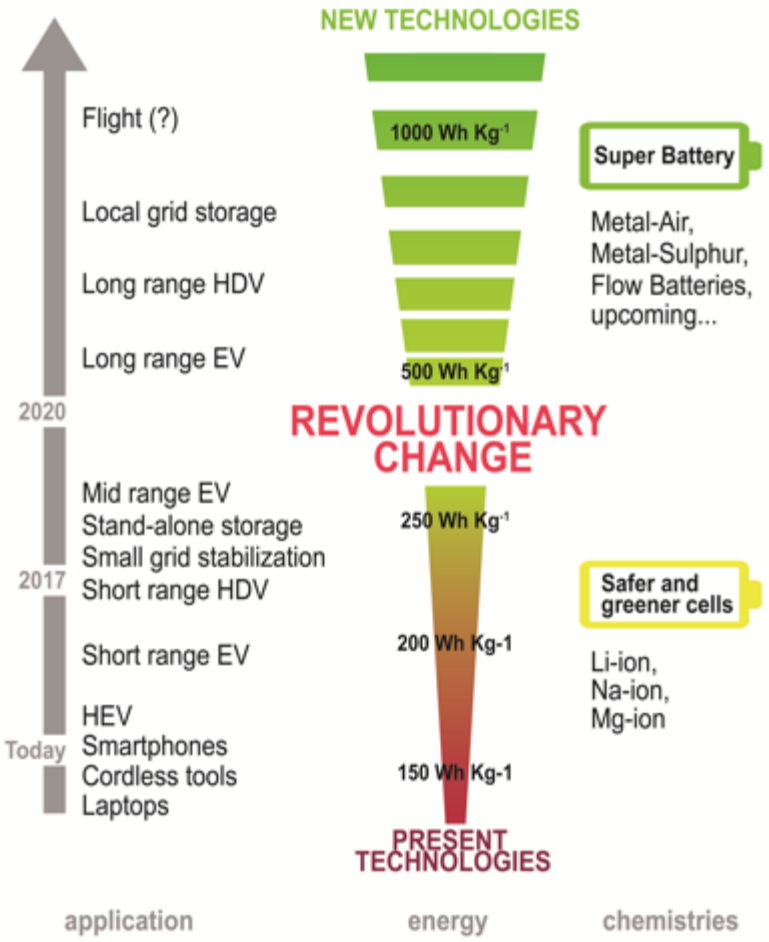
Energy Storage Challenges - A QUADRILEMMA

Battery uptake for grid, vehicles and beyond has major challenges to overcome……

2025



Li ions have perpetually tortuous, repeated voyages….

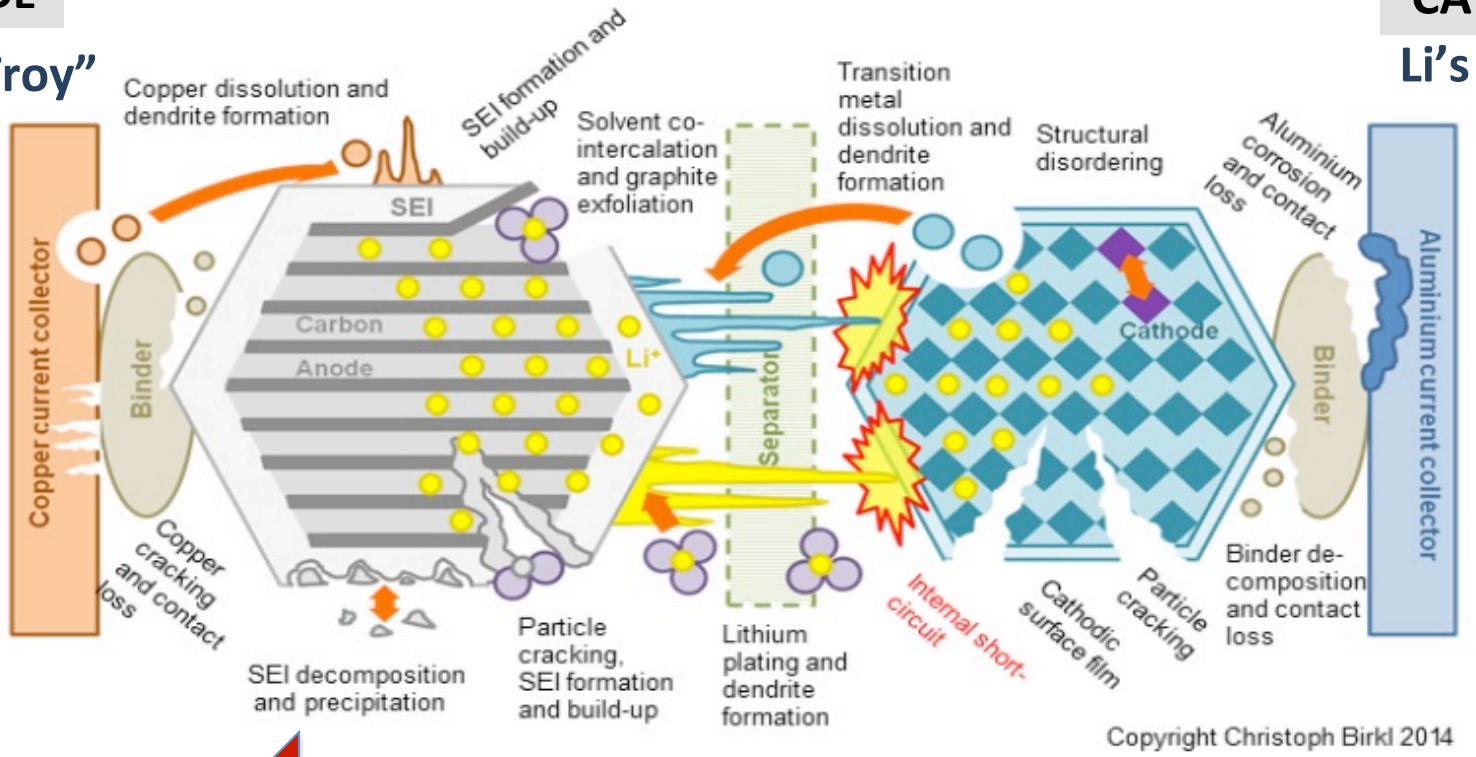
Discharge: *The Odyssey*

ANODE

Li's "Troy"

CATHODE

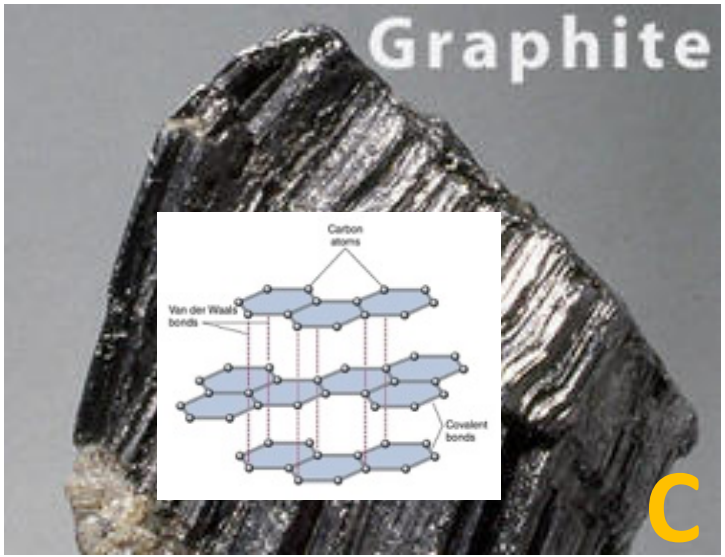
Li's "Ithaca"

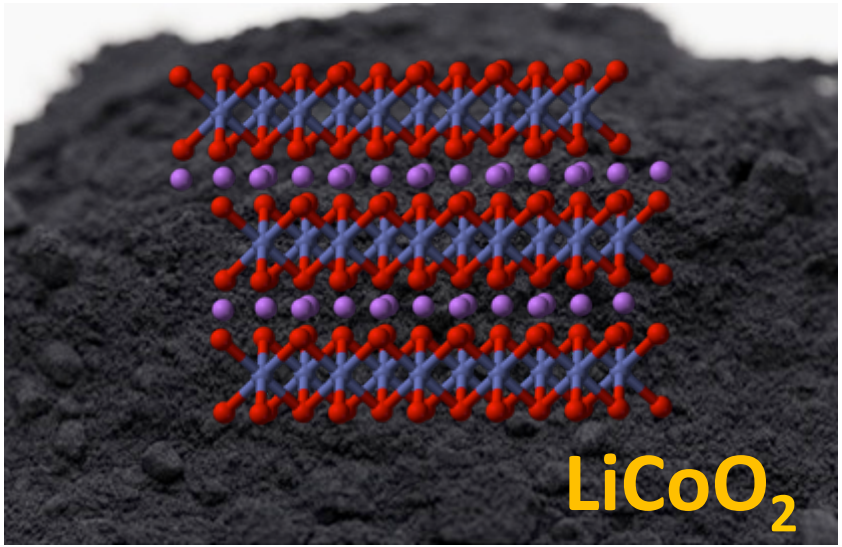


Charge: *The Iliad*

Battery Innovations - Evolution Not Revolution

Li-ion anode & cathode chemistry





More cathode material developments have been commercially successful (compared with anodes)

Material Dimensional Considerations and the rationale behind bio-inspiration.

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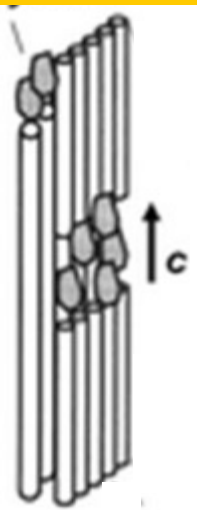
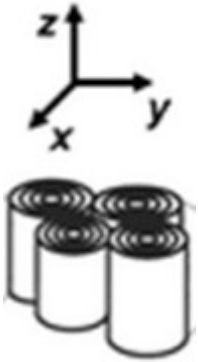
Why bio-inspired?

Biological microstructures are the most optimised and functional microstructures that exist.

Mineral crystals	Fibril	Fiber	Lamella	Osteon	Compact macrostructure
					
1nm	5-20 nm	50-100 nm	3 – 7 µm	10 – 500 µm	>1 cm

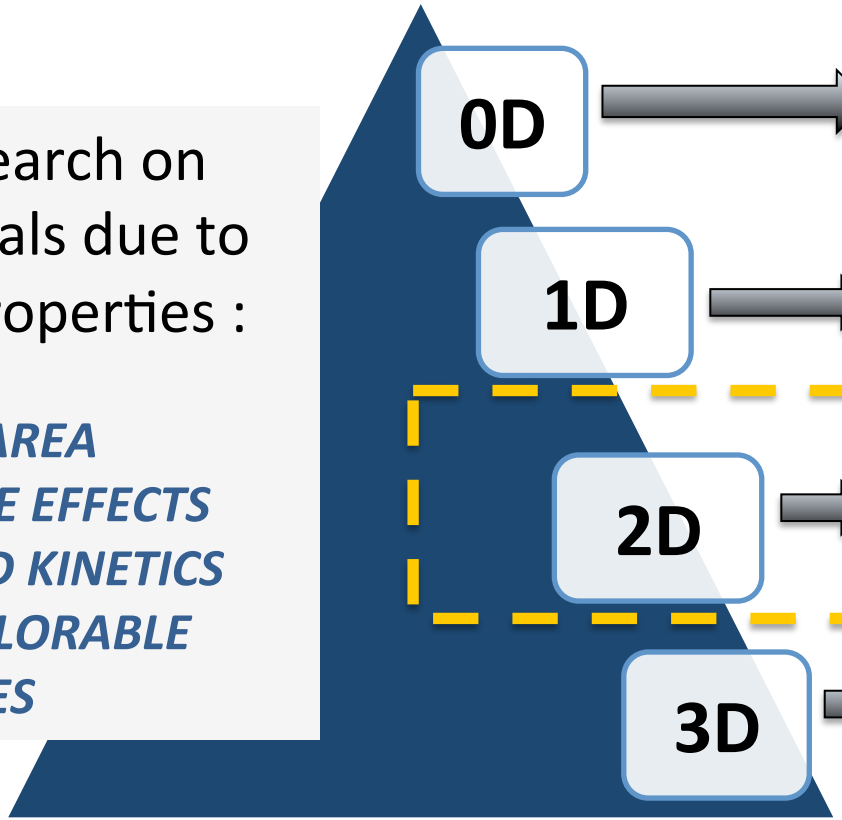
There are many opportunities to apply such structural arrangements in battery components

Nano-structured materials for energy storage: 2D or Not 2D?

That is the question…..

Intense research on nanomaterials due to desirable properties :

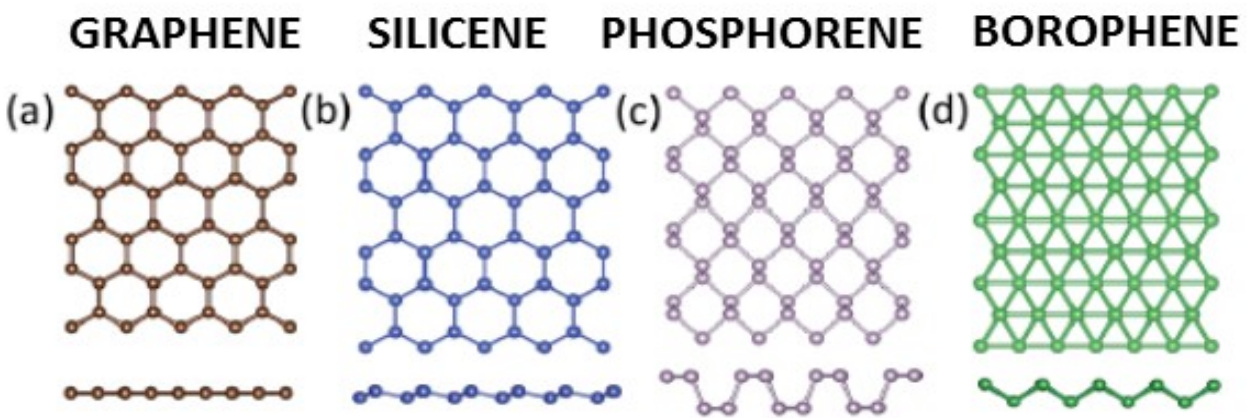
- *SURFACE AREA*
- *NOVEL SIZE EFFECTS*
- *ENHANCED KINETICS*
- *MANY TAILORABLE PROPERTIES*

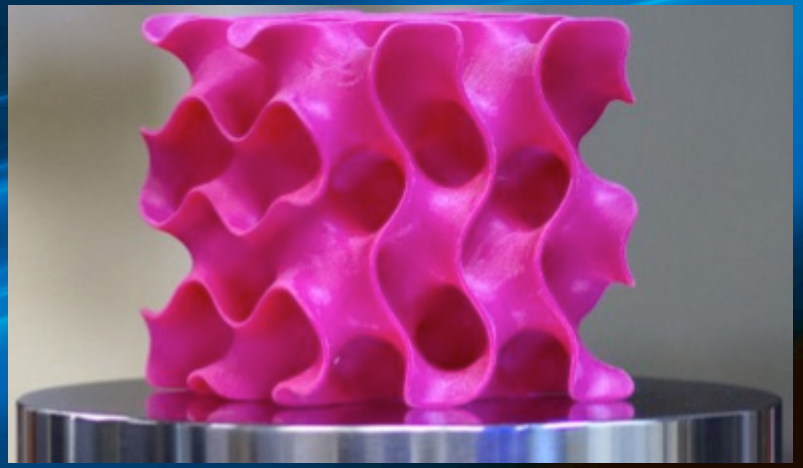


	Advantages	Disadvantages
0D	Short diffusion pathways, good rate capability	Unstable and difficult to make
1D	High capacity, strain relaxation, rate, electrical connectivity	Low surface area & diffusion rate, scalable manufacture
2D	Small crystalline size, high surface area, large SA:V, ease of synthesis	Energy density limits, SEI
3D	Large SA:V, high capacity, structural stability	SEI

Property Advantages of 2D Materials

- Large **surface areas** and **interlayer spaces** of 2D materials e.g. graphene & transition metal dichalcogenides (TMDs) provide an ideal framework to store lithium (or sodium) ions electrochemically
- Layered transition metal sulphides e.g. MoS_2 have weak interplanar bonding (van der Waals interactions) – Li ions can be inserted and accommodated with less severe volume expansion





2D into 3D

Energy Innovation Centre

Materials & Electrochemistry Group

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2D-3D Anode Developments for Li & Na-ion Energy Storage

AMorpheus (EPSRC) 2D Alloys	AtMoS$_2$pheric (EPSRC) 2D Graphene Composites
Amorphous Si-Sn anodes	**MoS$_2$-graphene hybrids**
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UCL	UCL
DE MONTFORT UNIVERSITY LEICESTER	

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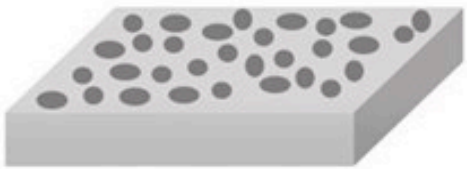
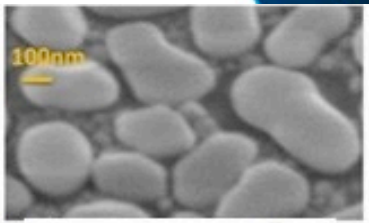
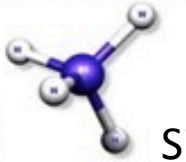
AMorpheus – Plasma enhanced CVD SnSi NWs



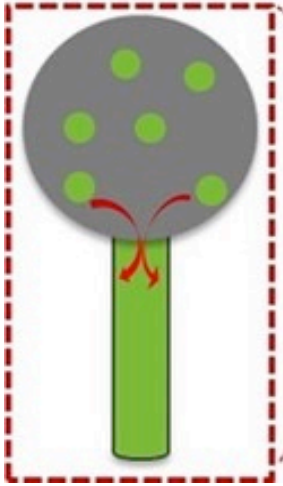


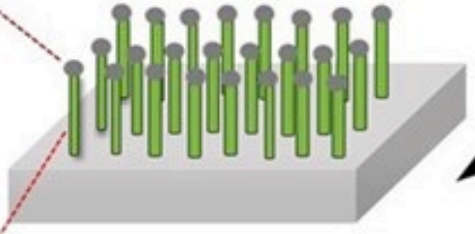
Self-assembly of Sn nano-droplets



Silane

Vapour-Liquid-Solid Growth Mechanism





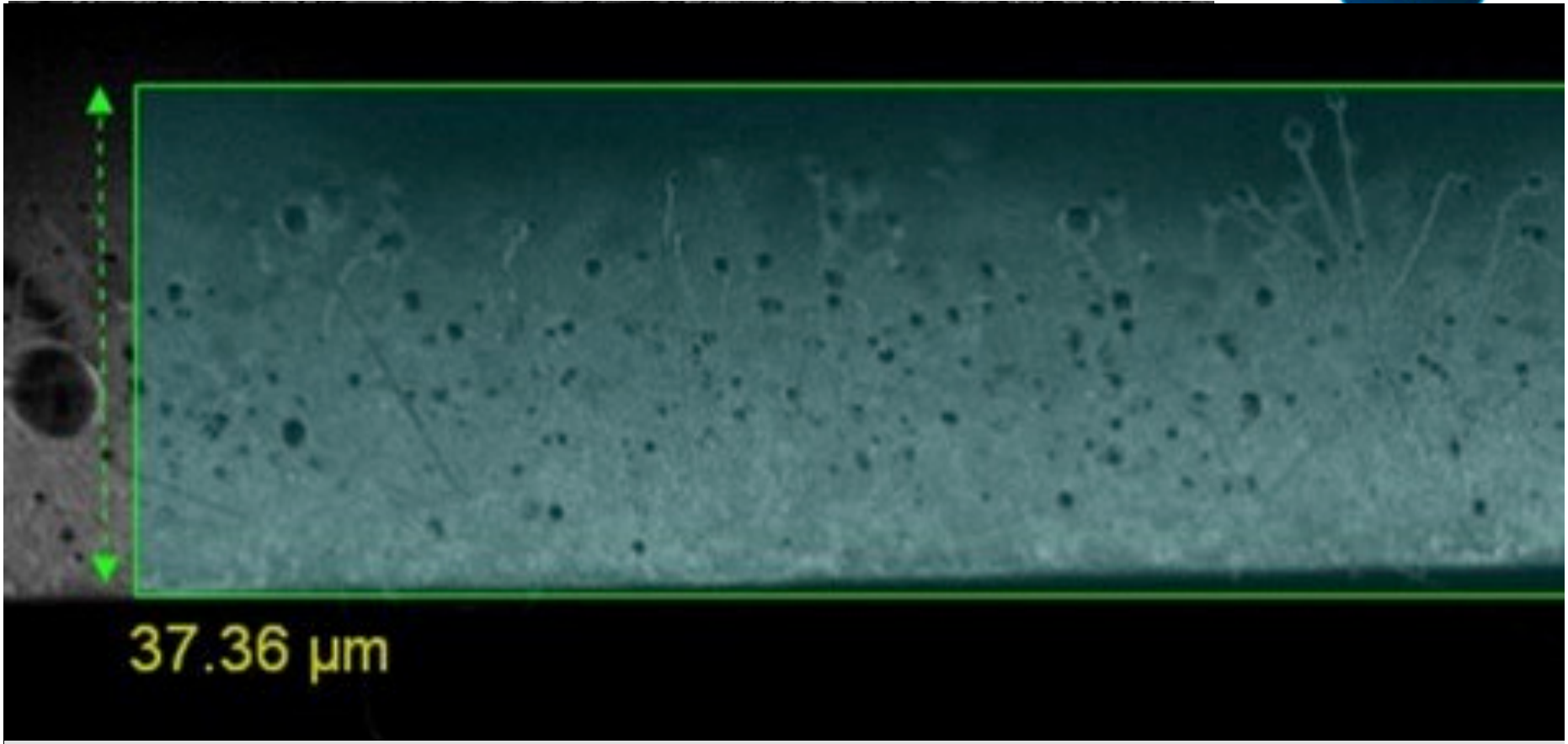
Liquid-phase transport causes a small supersaturation driving precipitation of new Si at the Sn-Si interface

Absorption on the droplet maintains conc. gradient of the semi-cond. component counteracted by a diffusion current

2D Sn-Si hybrid NW

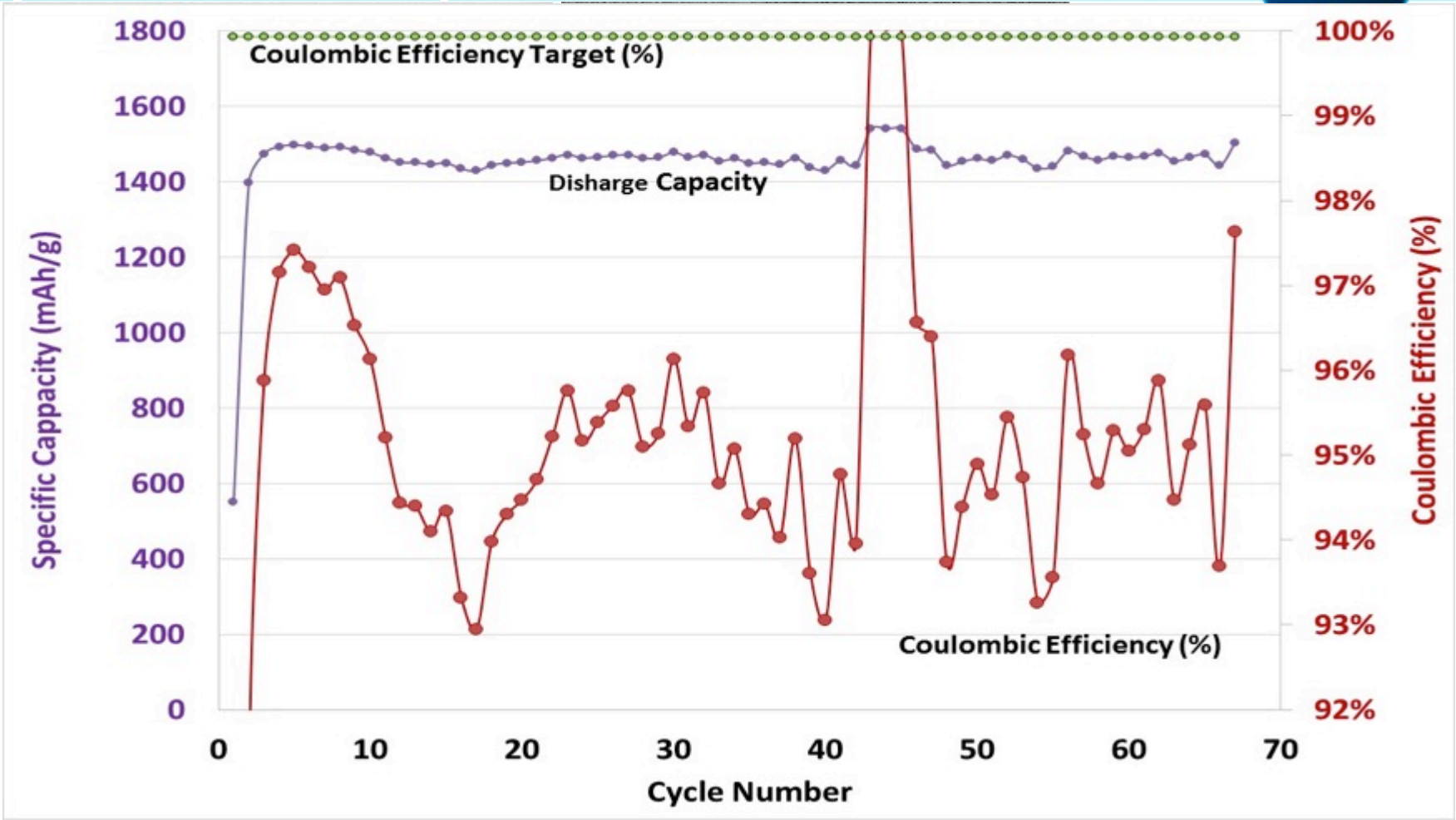
Bottom-up NW growth

Versatility of Coating 3d Substrate Current Collectors



Practical Film Thickness for energy density

Crystalline & Amorphous 2D Nanowires



Integrating 2D Materials

EPSRC
Engineering and Physical Sciences Research Council

Fellowship: AtMoS$_2$pheric

ERA ENERGY RESEARCH ACCELERATOR
At the forefront of energy transformation

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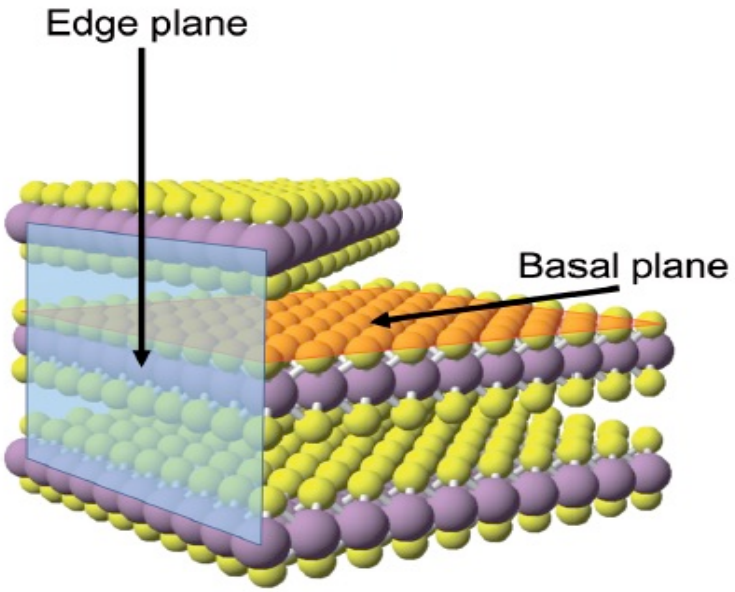
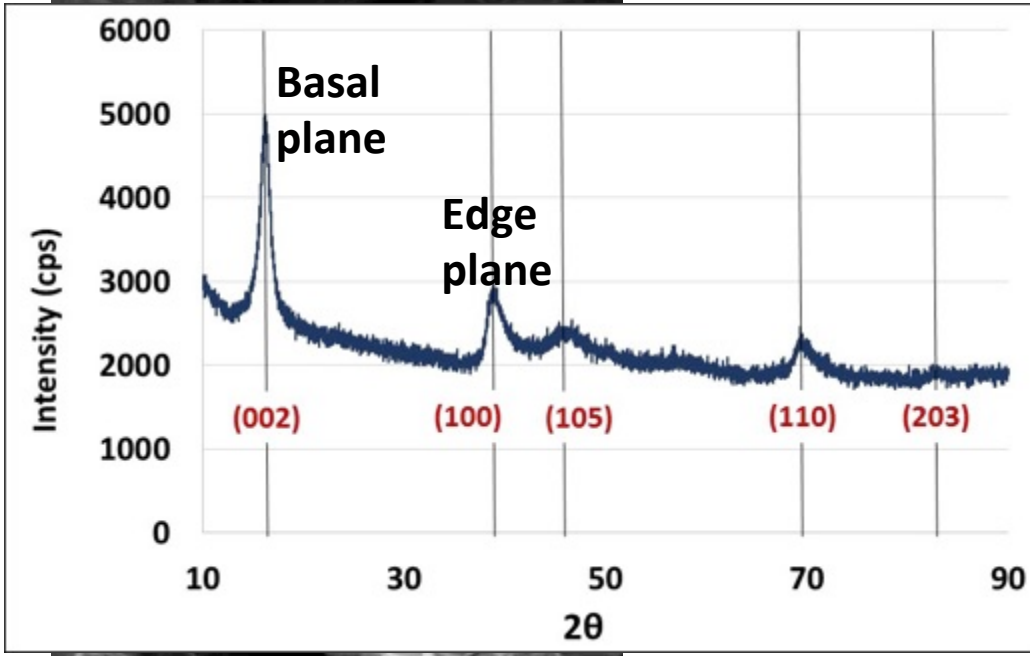
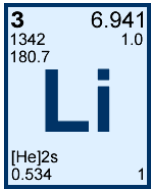
Method 1

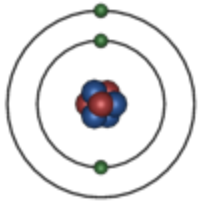
Synthesis of Molybdenum Disulfide Nanoflowers (MoS_2)

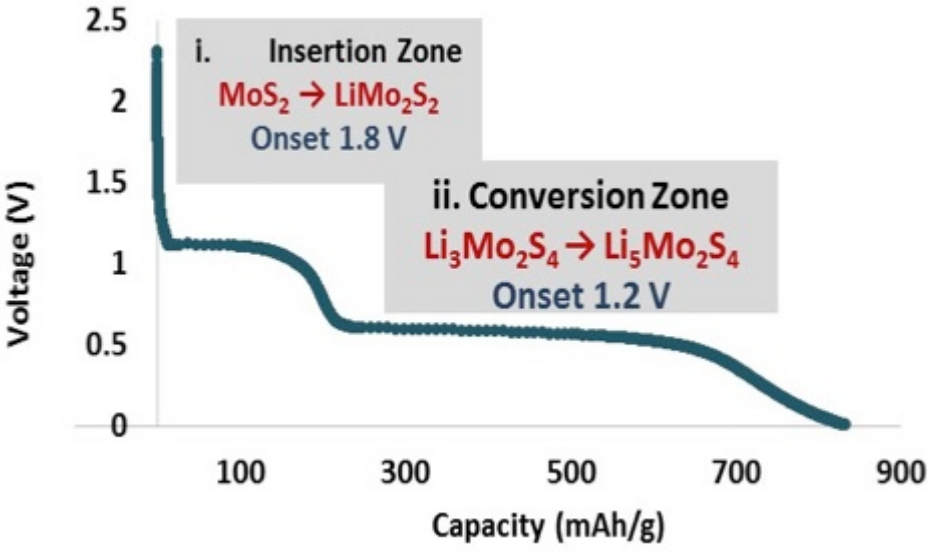




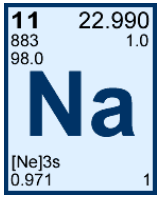
Li-ion Energy Storage

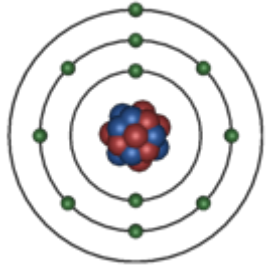


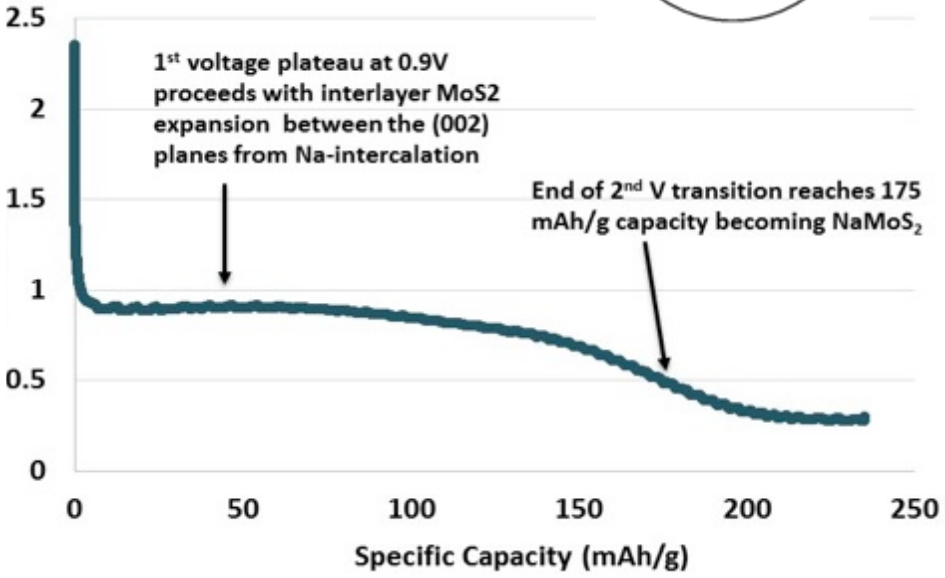




Na-ion Energy Storage

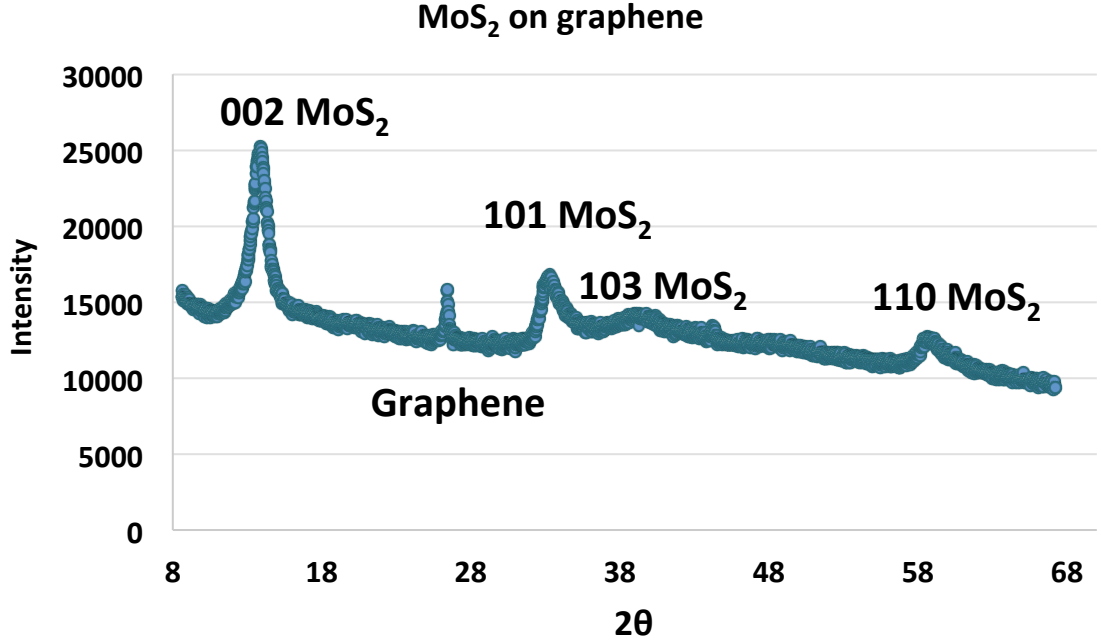






Method 2

300 nm



Uniform & stable MoS_2 coverage

2D Material as multi-functional Enhancing Additive

Silicon Anode Research

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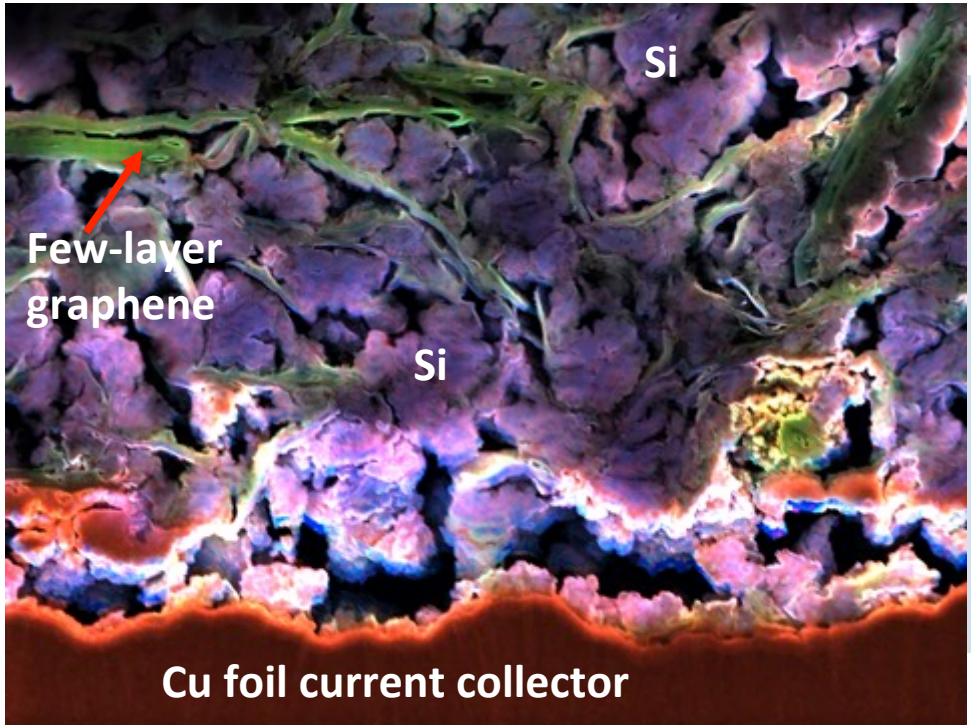
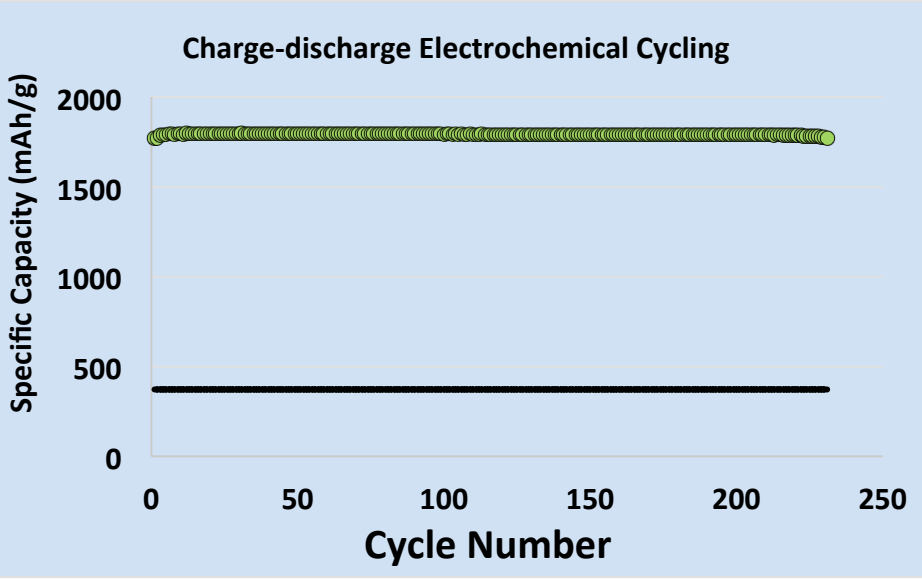
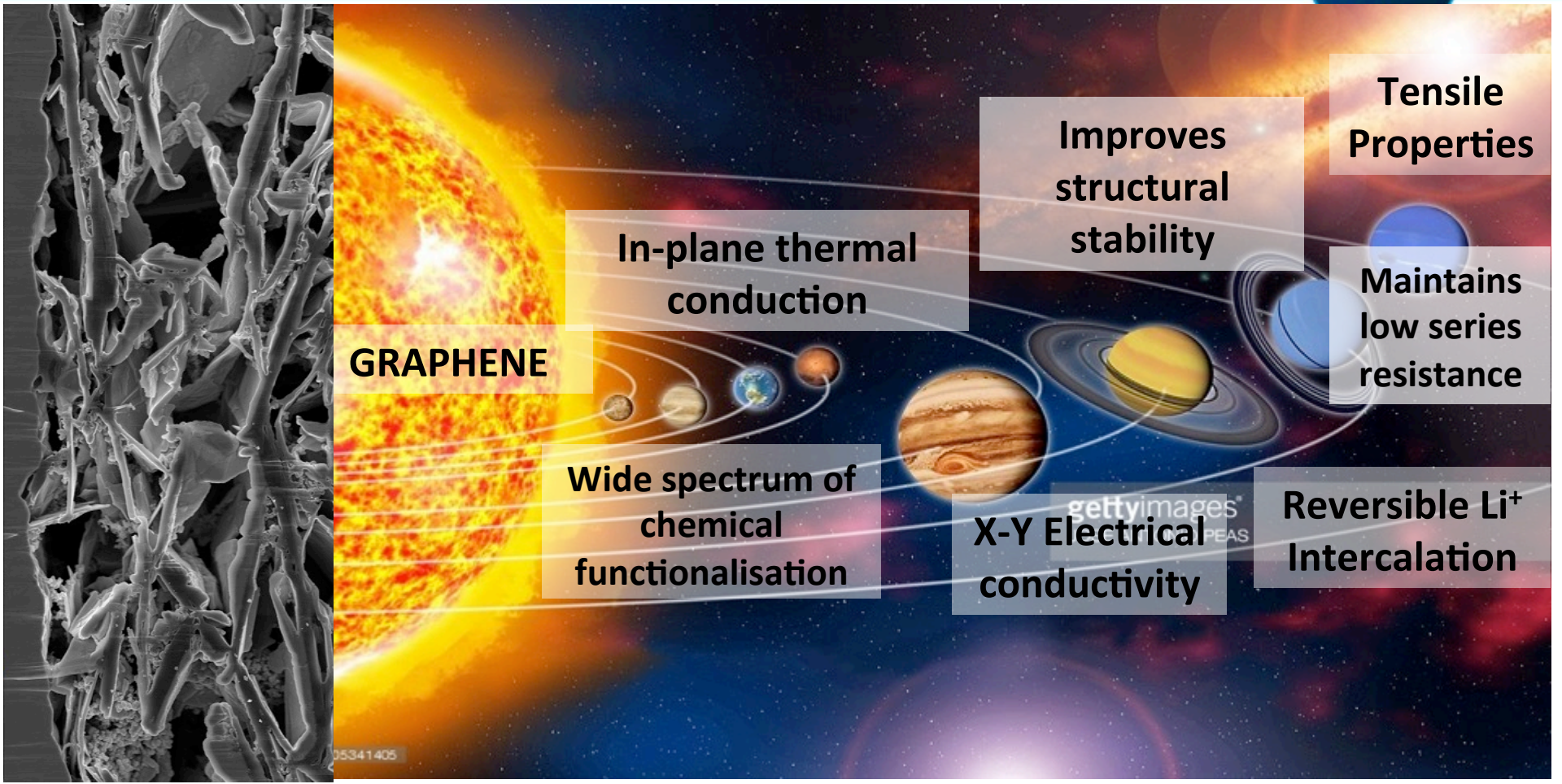
Si-graphene Composite Microstructures





Graphene: Holistic Performance-enhancing Substance!



Conclusions

- Integrating select 2D Li host materials into 3D morphologies is beneficial to electrochemical performance (surface area, diffusion paths…)

- Composite 2D-3D microstructures incorporating graphene offer multiple functions in energy storage systems

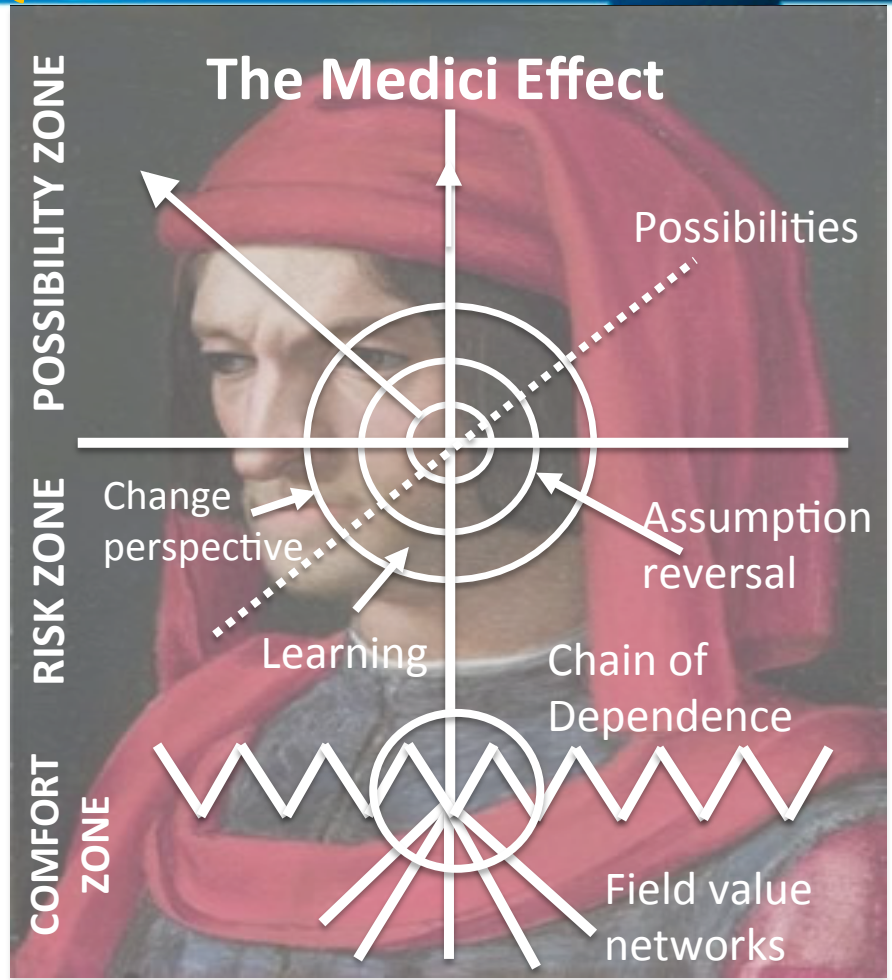
Recommendation: There is a need to explore advanced manufacturing methodology for nanostructured materials.

Thank you for listening….. Any Questions?

The Medici Effect

(relevant to energy storage innovations)

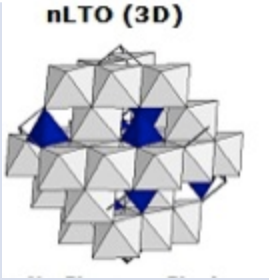
"When you step into an intersection of fields, disciplines, or cultures, you can combine existing concepts into a large number of **extraordinary new ideas**."

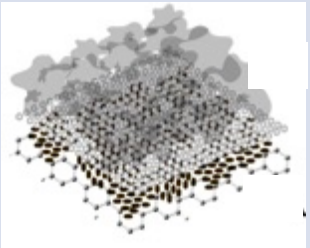


Multi-scale materials for optimised microstructures

(1) Active Materials

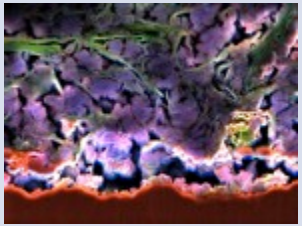
µm clusters of nm particles





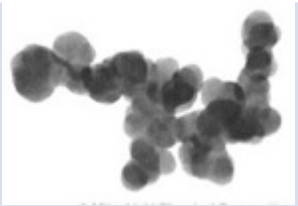
Hybrid combinations

Composites



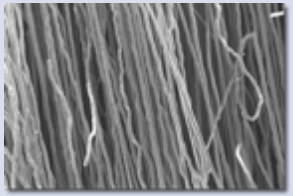
(2) Matrix of Conductive Additives

Carbon black

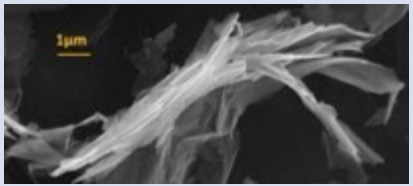


CNTs

VGCF

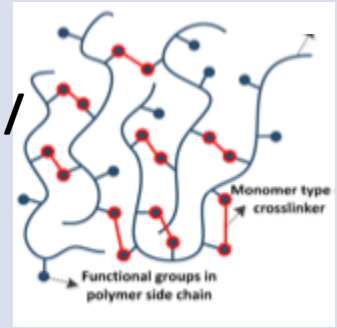


FLG

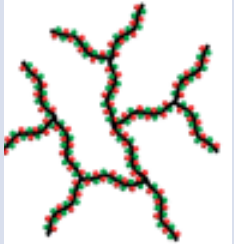


(3) Polymer Functionality & Hybrids

Configuration / Property combinations



Branching + chemistry modifications for max. interactions



Cross-linking with M^{x+} ions