



Nissan Leaf

Schwarz-Primitive structured electrodes for lithium-ion battery via 3D printed wax templating

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University of Oxford
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1st November



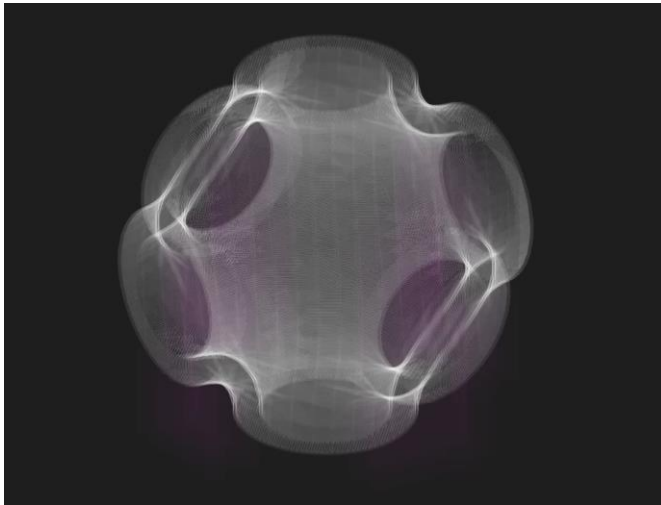
WHAT IS AN SCHWARZ-PRIMITIVE STRUCTURE?

Schwarz-Primitive
structured electrodes for
lithium-ion battery via 3D
printed wax templating



What is a Schwarz primitive surface (SP)

Two intertwined congruent labyrinths, each with the shape of an inflated tubular version of the simple primitive cubic lattice.



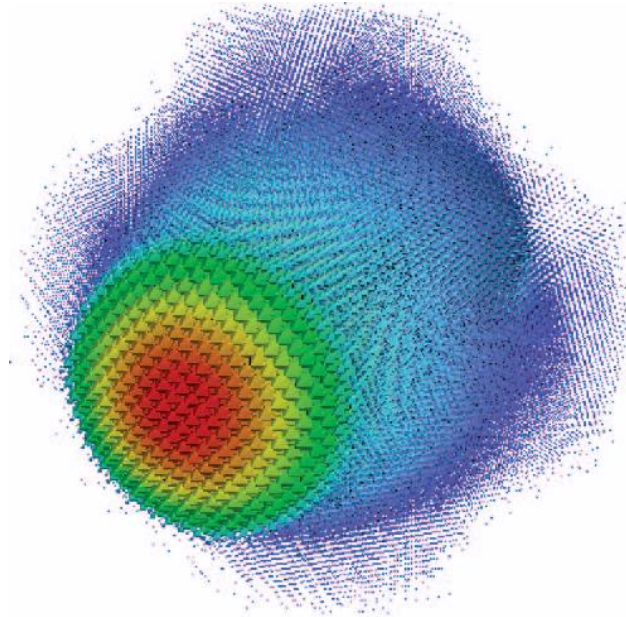
cubic symmetry



Why is a Schwarz-Primitive structure important

1) Large fluid permeability

2) Optimizing microstructures for simultaneous transport of a pair of transport properties



Any pair of the following:

- thermal conductivity
- electrical conductivity
- diffusion coefficient
- dielectric constant
- magnetic permeability

Phys. Rev. E **72**, 056319 (2005).

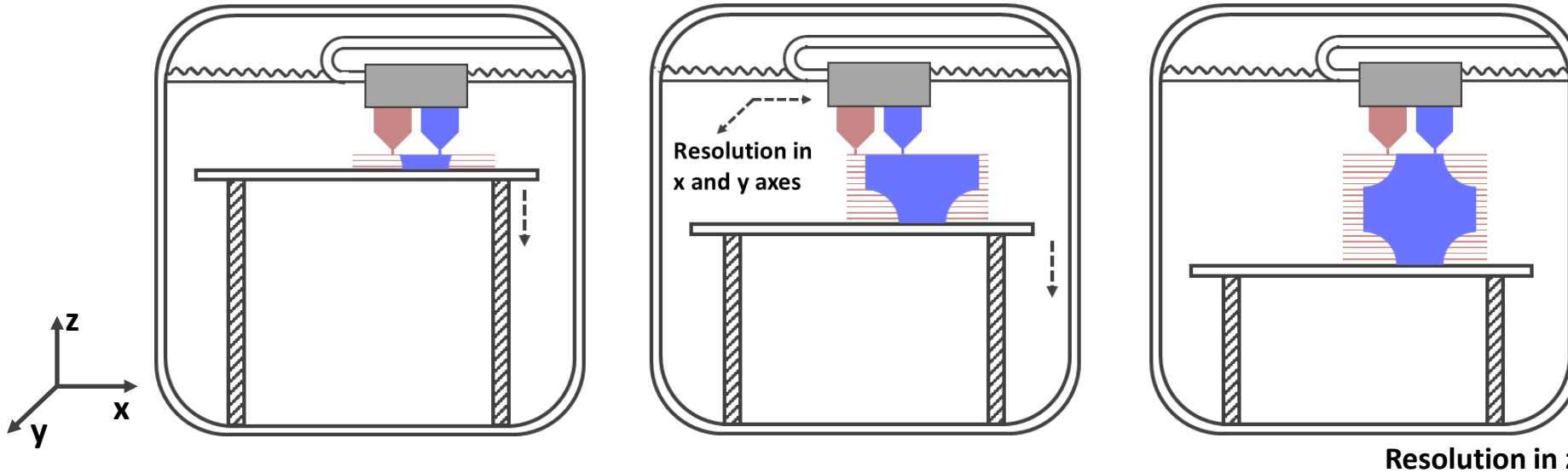
Phys. Rev. Lett. **89**, 266601 (2002).

How to engineer such a structure for battery application?

2

Permeability: property of membranes and other structures to permit passage of light, heat, gases, liquids, metabolites, and mineral ions.

3D PRINTING - MATERIAL JETTING:



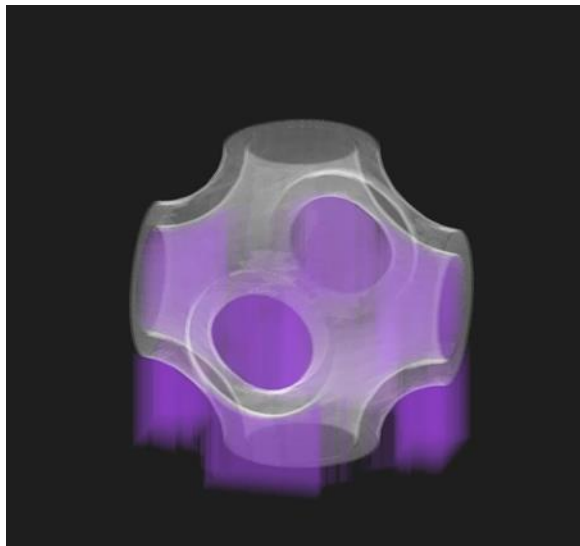
Schwarz-Primitive structured electrodes for lithium-ion battery via 3D printed wax templating

Advantages:

- Potential for large area
- Commercially available
- High resolution

Disadvantage: Slow

Supporting material



How to make a SP structured electrode?

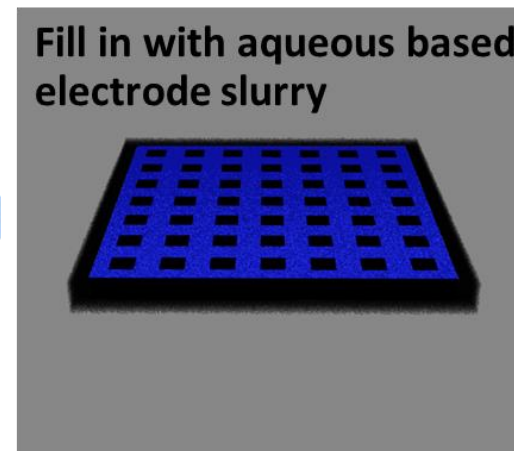
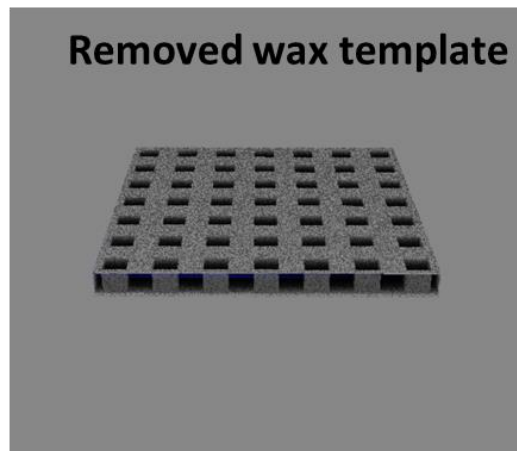
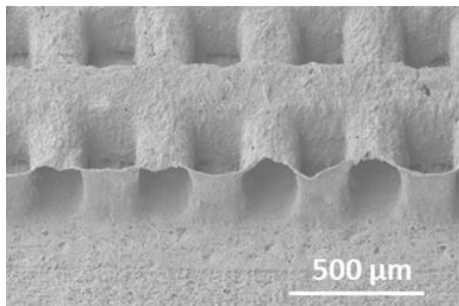
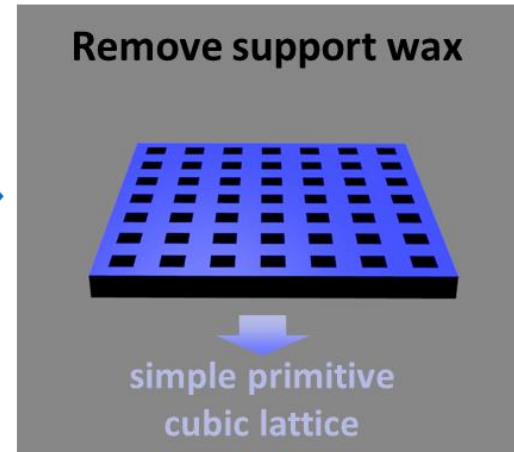
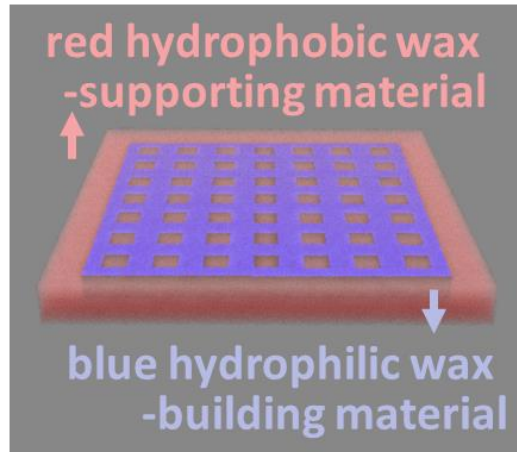
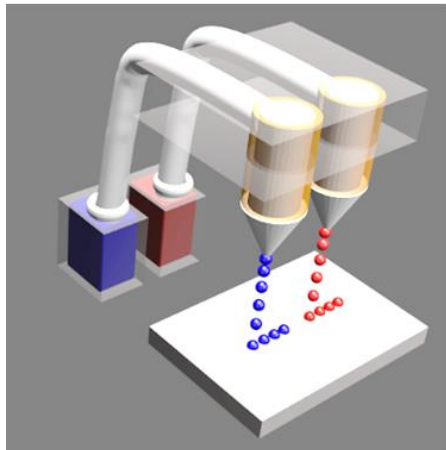
Challenges (mixing active materials into a wax):

- Low conductivity
- Block the printhead
- Removing supporting material

a template with a reversed structure

HOW TO ENGINEER AN SP STRUCTURED ELECTRODE

Schwarz-Primitive
structured electrodes for
lithium-ion battery via 3D
printed wax templating



Advantages of wax templating:

- Many materials
- Low melting point
- Used in other industry

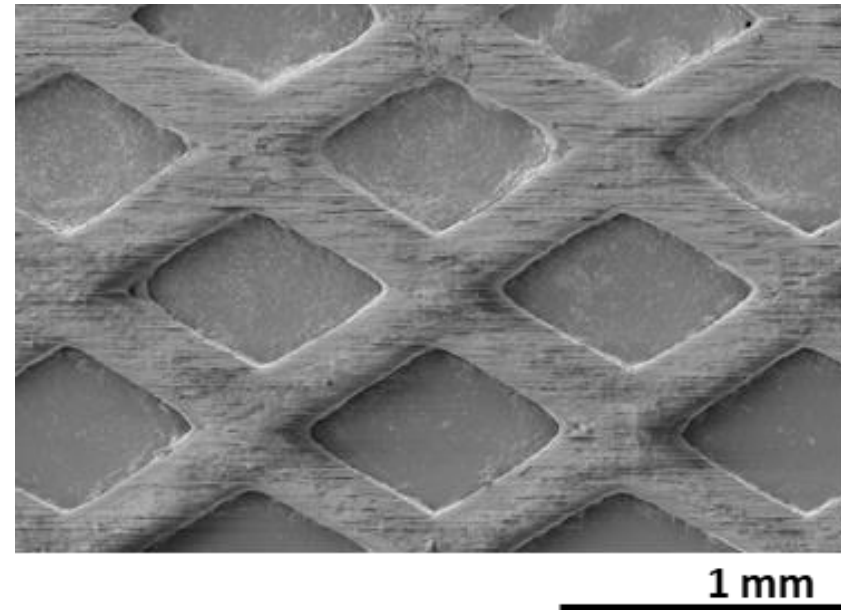
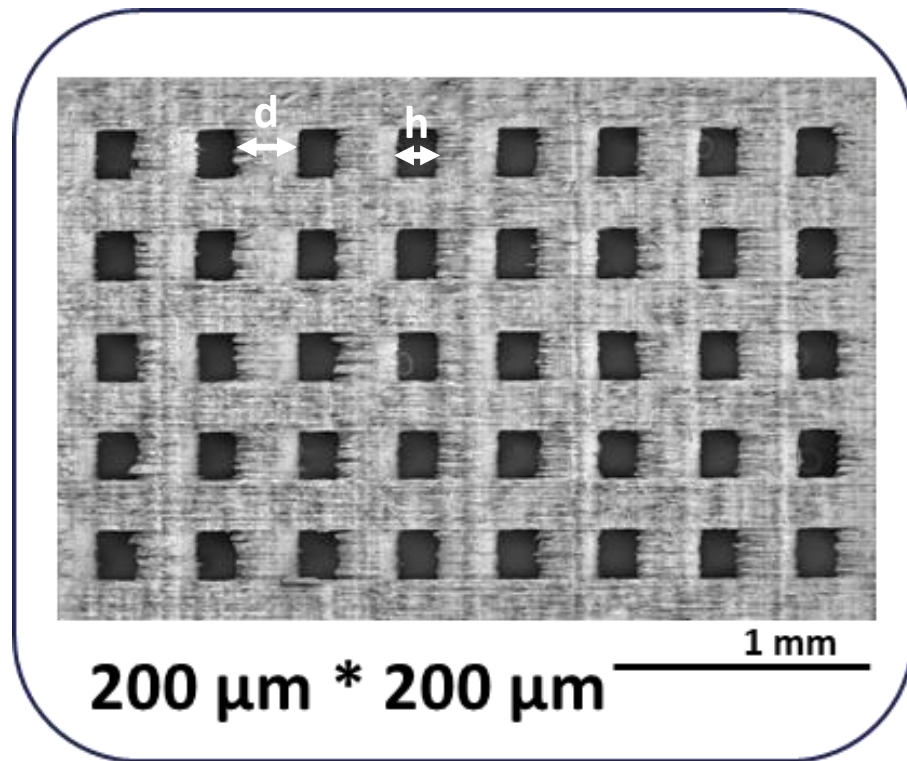
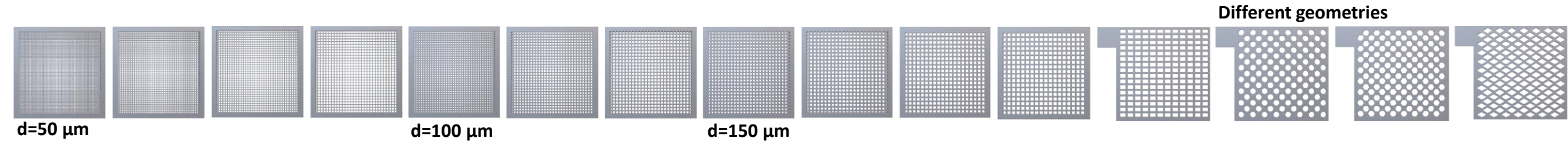
Wax template with a reversed
structure of an SP surface

3 outputs:

1. Wax templates
2. Structured electrodes
3. Thick electrode with structured C network)

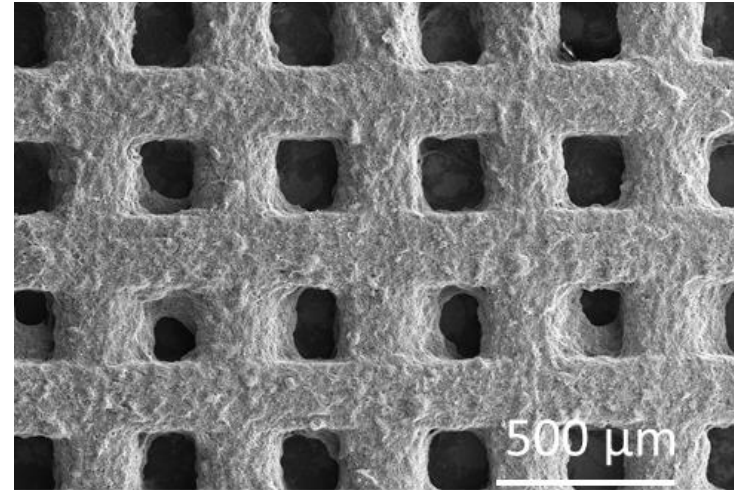
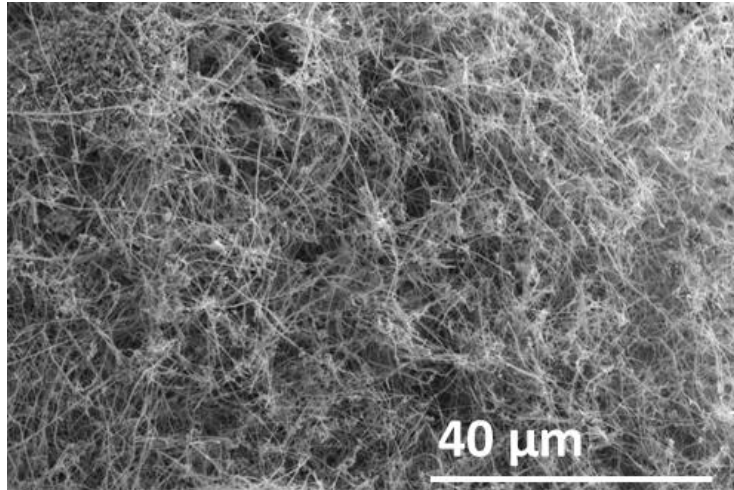


OUTPUT 1: 3D PRINTED WAX TEMPLATES:

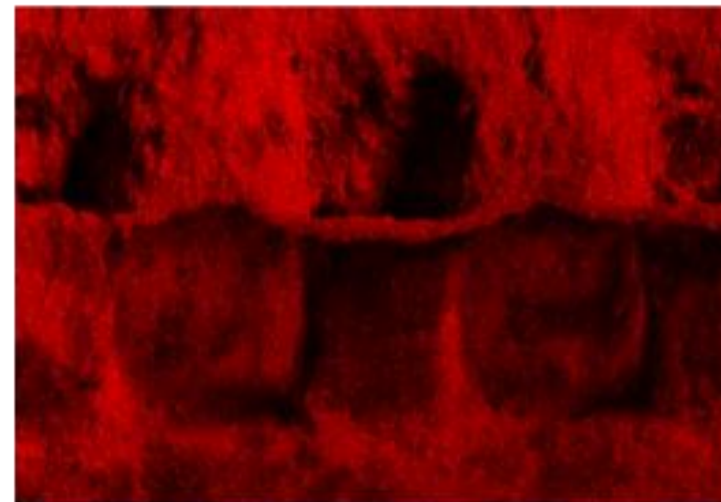
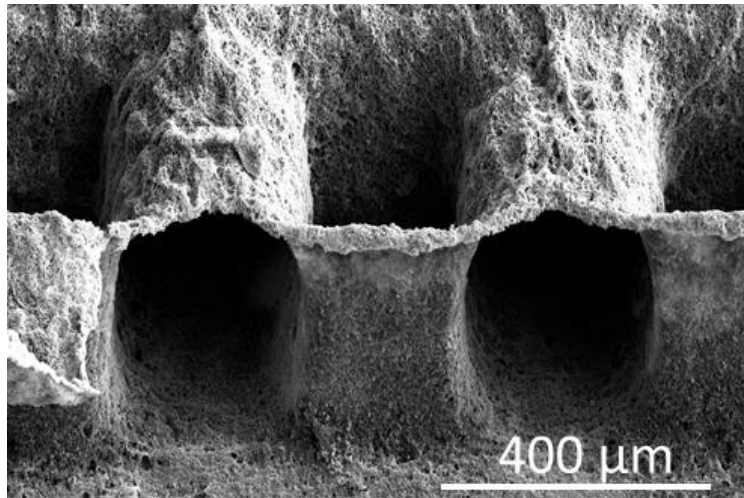


Wide design space

OUTPUT 2: TEMPLATED ANODES: CNF (CARBON NANOFIBERS)



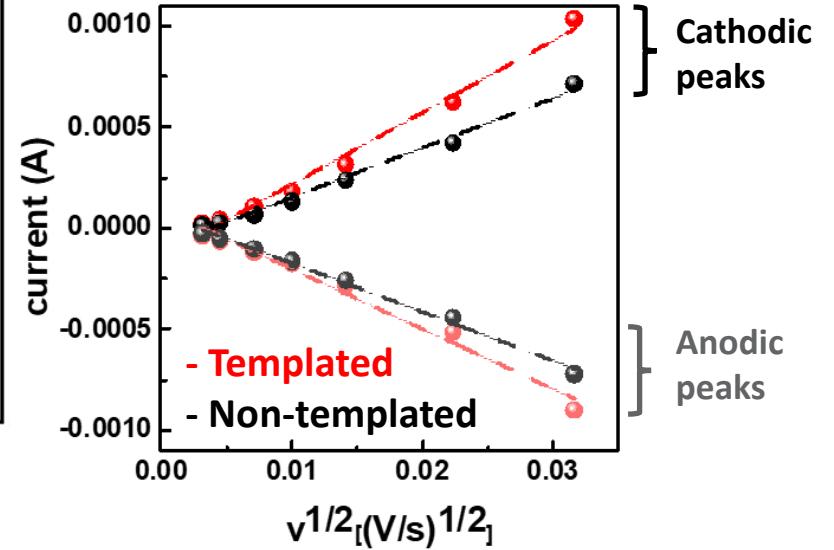
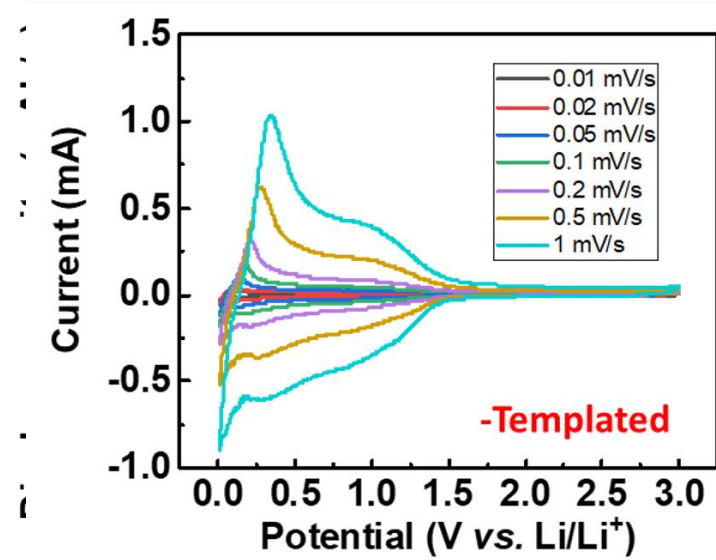
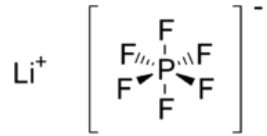
C K series



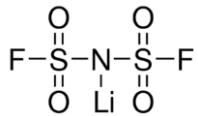
PERFORMANCE OF TEMPLATED CNF ANODES



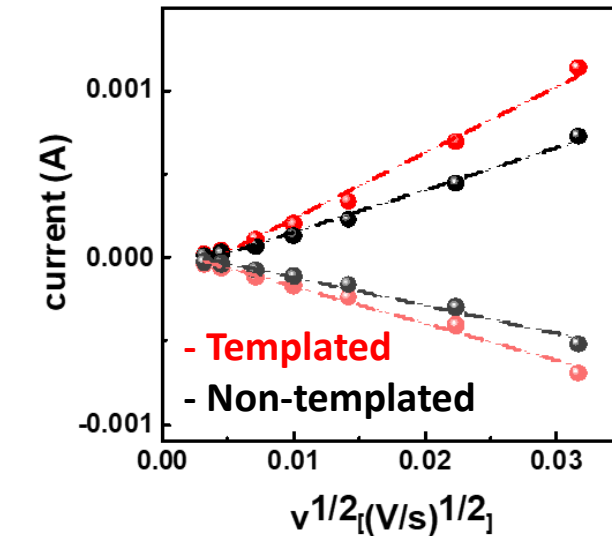
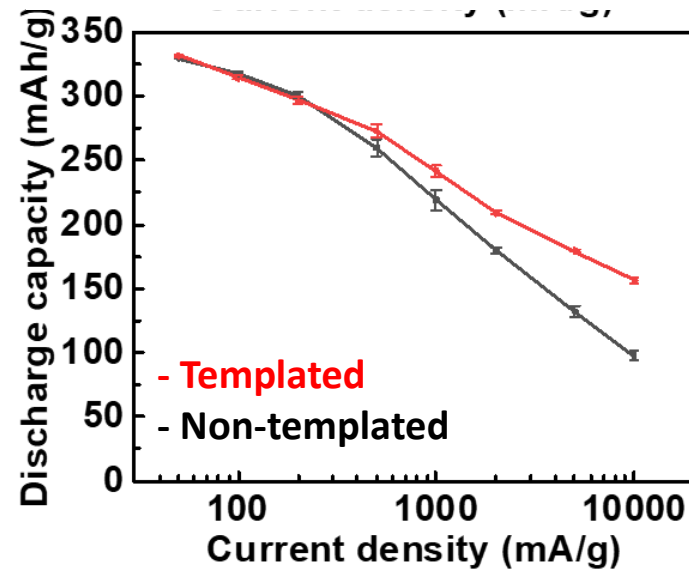
LiPF₆ electrolyte



LiFSI electrolyte



half-cell
high reproducibility



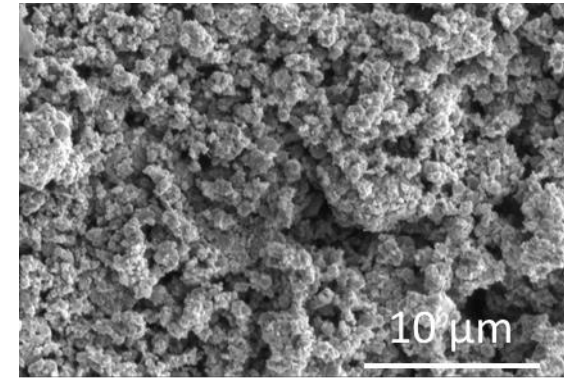
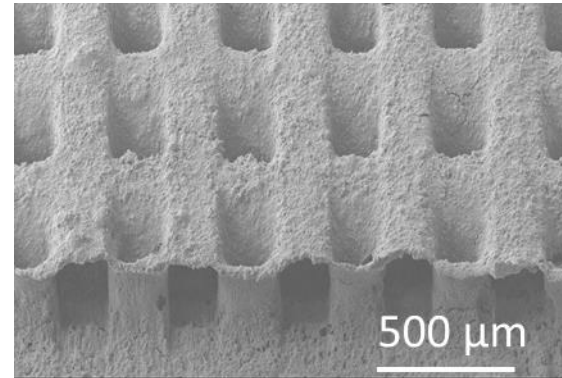
LiPF₆: Lithium hexafluorophosphate
LiFSI: Lithium bis(fluorosulfonyl)imide

OUTPUT 2: TEMPLATED ELECTRODES (BOTH ANODES AND CATHODES):



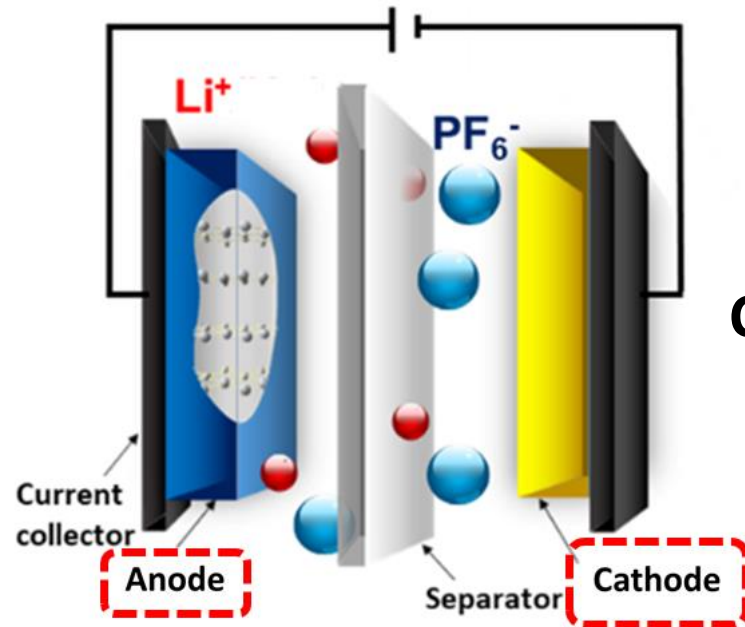
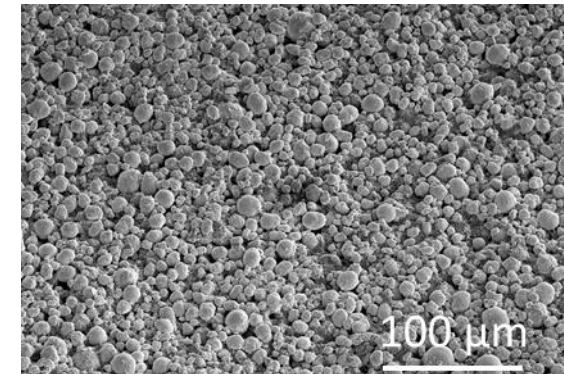
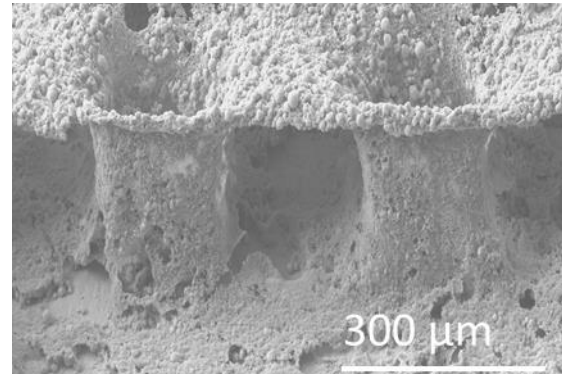
Cathode: templated LFP

LFP raw material

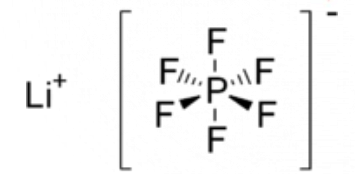
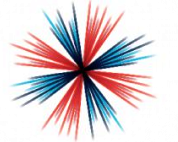


Cathode: templated NMC

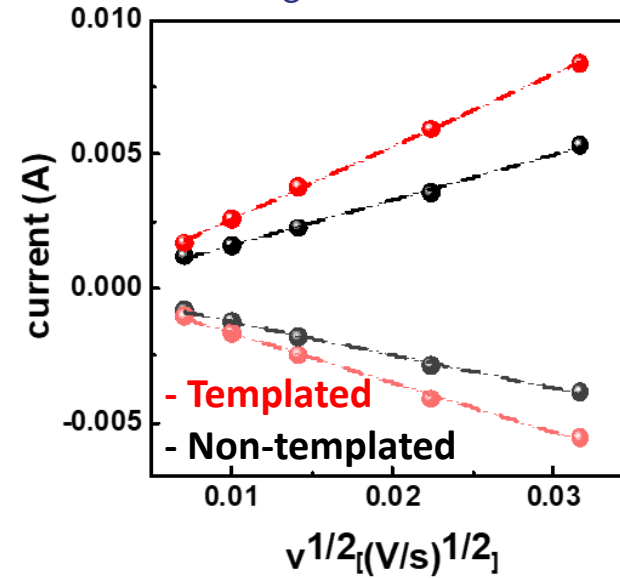
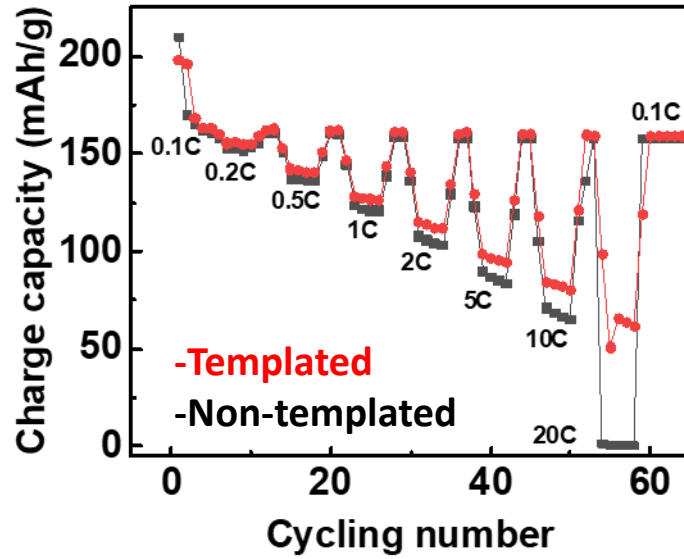
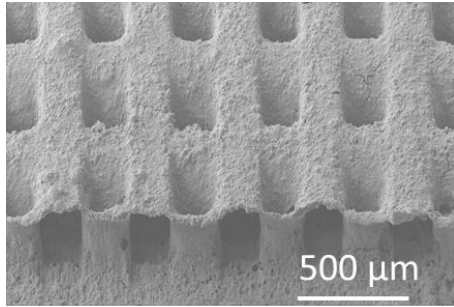
NMC raw material



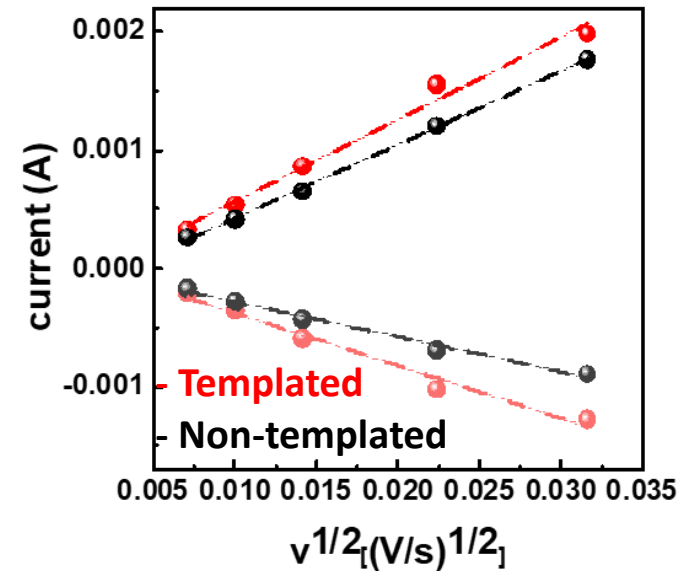
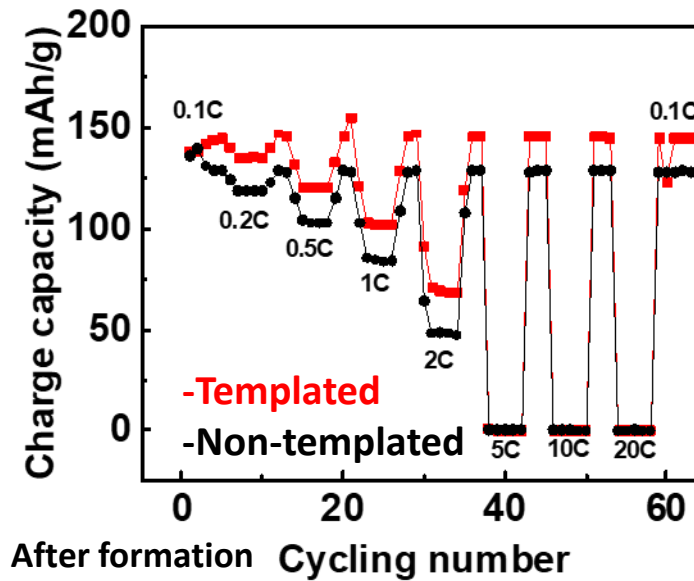
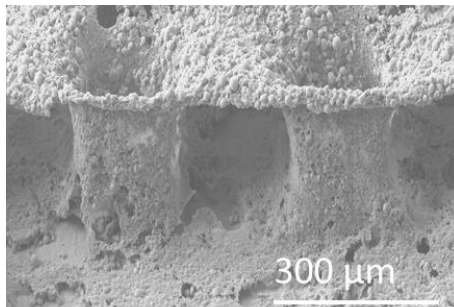
PERFORMANCE OF TEMPLATED LFP CATHODES (LIPF₆ ELECTROLYTE)



LFP



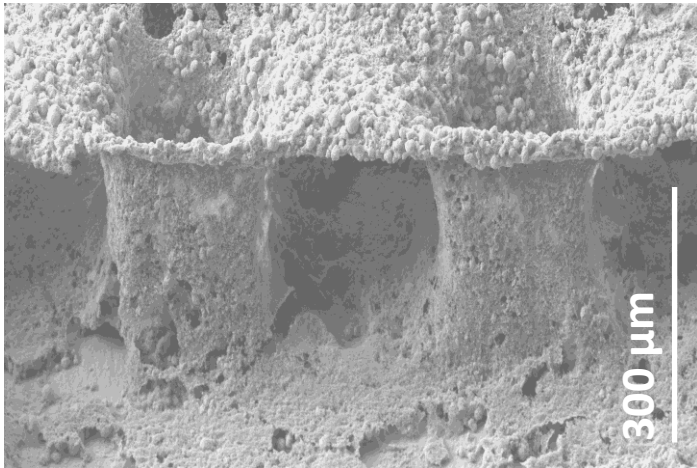
NMC



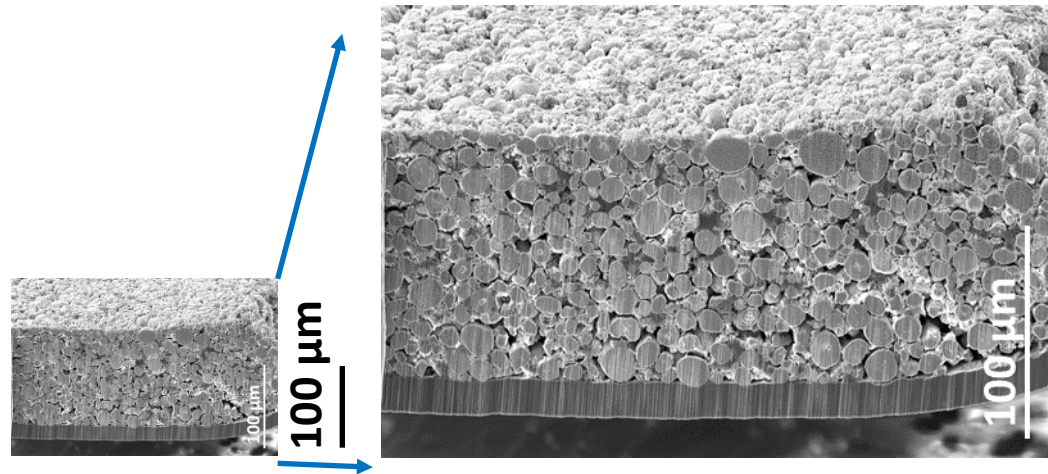
TEMPLATED ELECTRODE VS. NON-TEMPLATED ELECTRODE



Templated



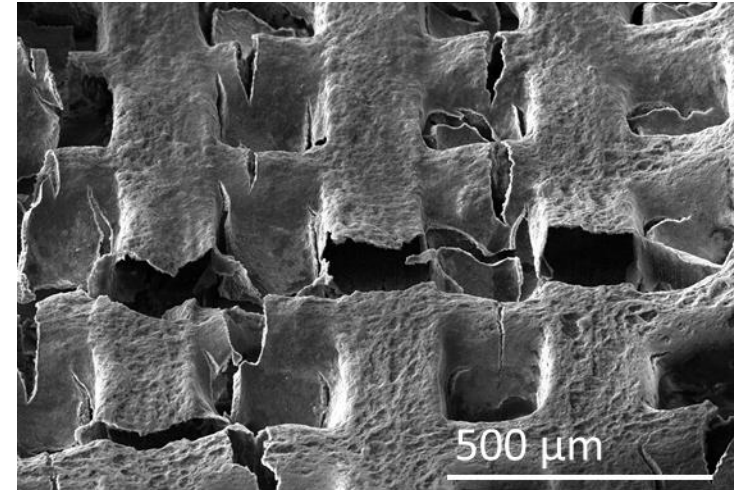
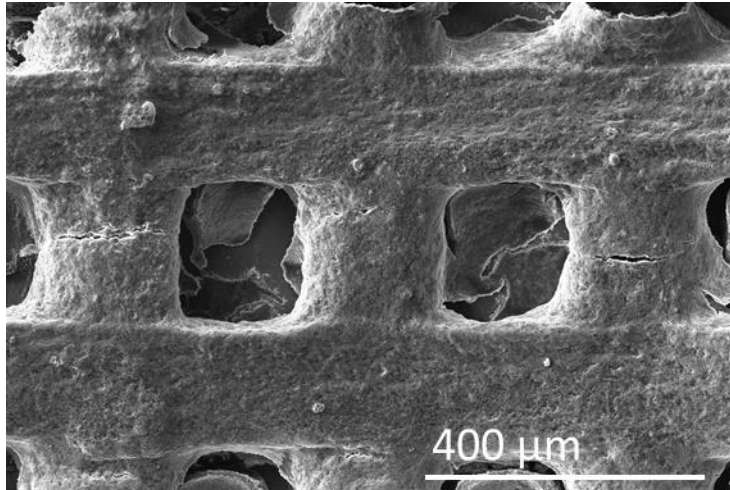
A baseline electrode (pilot line)



Gravimetric electrochemical performance improved but volumetric energy/power density undermined by a high porosity.

OUTPUT 3:

MORPHOLOGY OF TEMPLATED C SP LATTICE (C_{65})

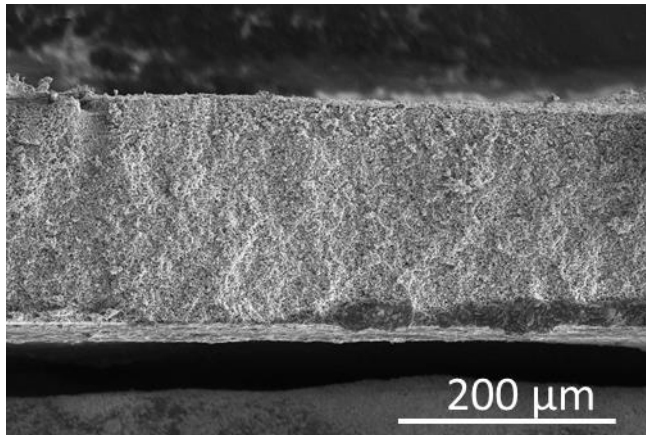


OUTPUT 3:

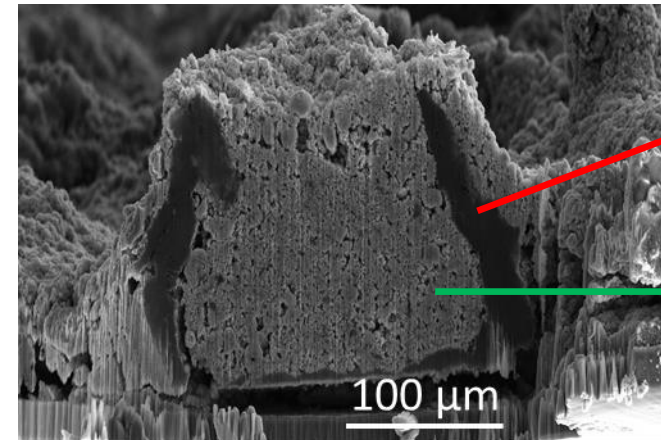
MORPHOLOGY OF LFP CATHODES WITH TEMPLATED C SP LATTICE



LFP electrode



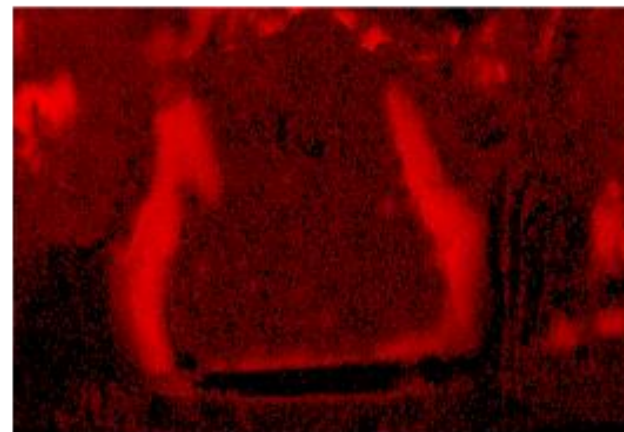
Choose one unit to do cross-section



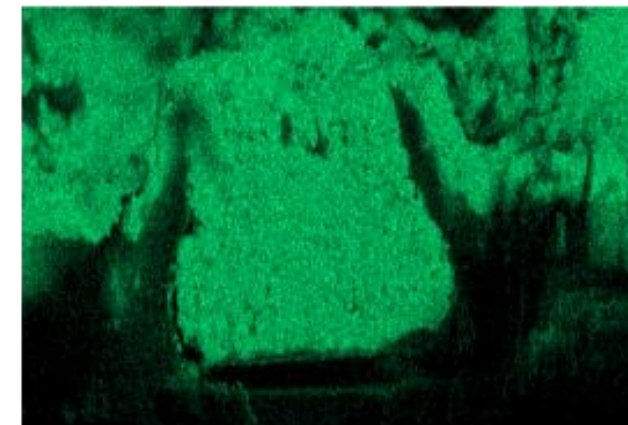
C₆₅ SP lattice

Refilled LFP aqueous slurry

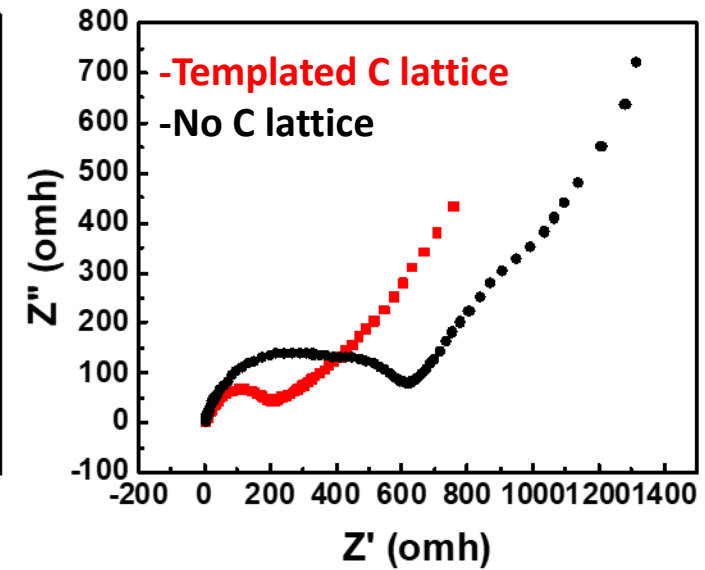
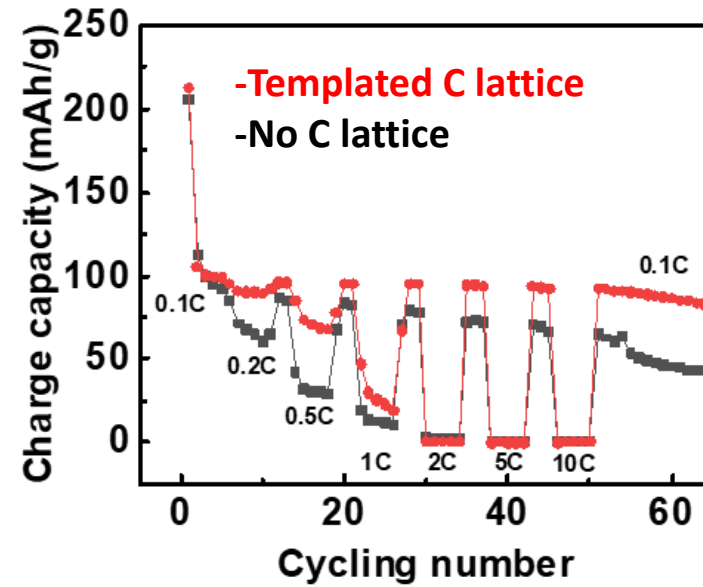
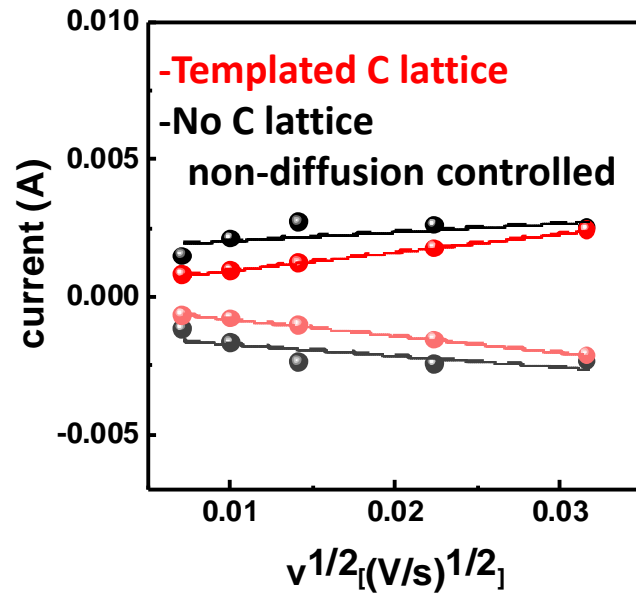
C Kα1_2



P Kα1



MORPHOLOGY OF LFP ELECTRODE WITH TEMPLATED C SP LATTICE

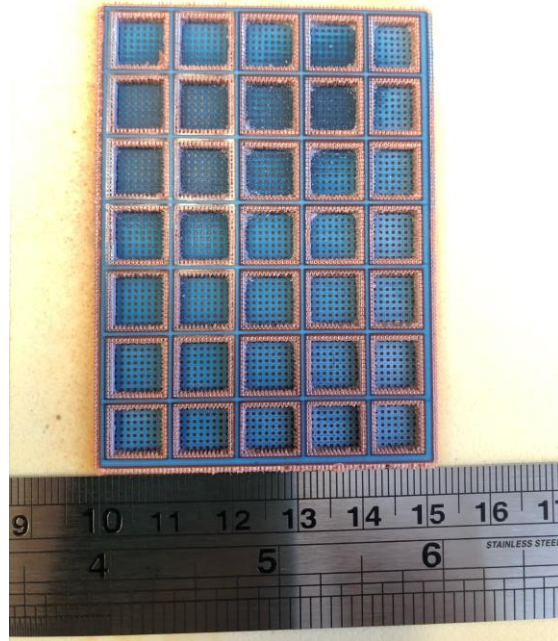
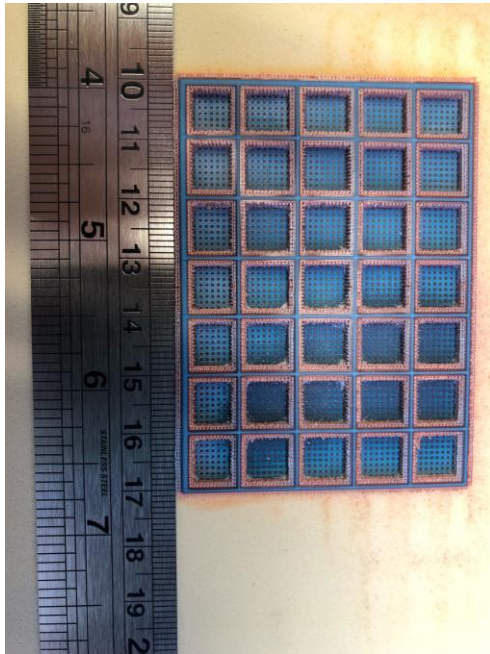


FUTURE PLAN:

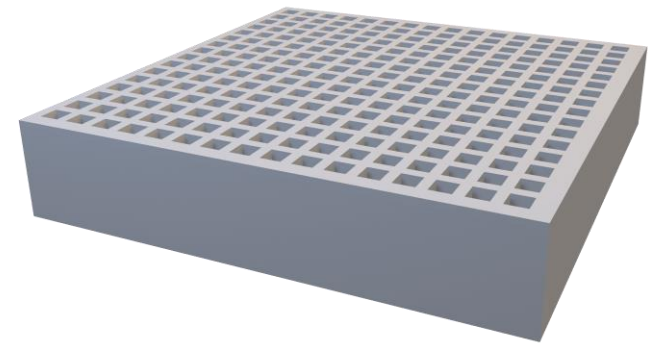


Larger electrode – for pouch cells

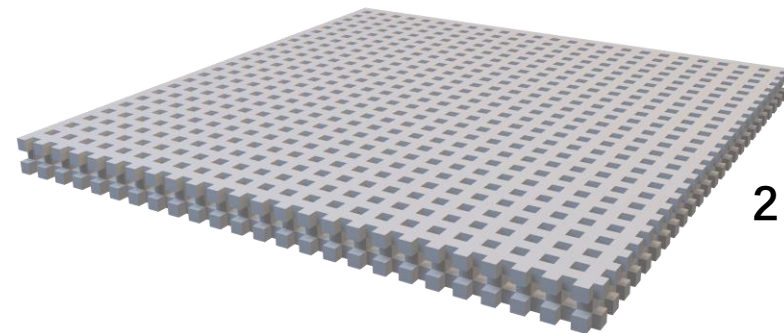
Wax template (5*7cm)



Thicker electrode – 1 layer vs. 2 layers



1 layer

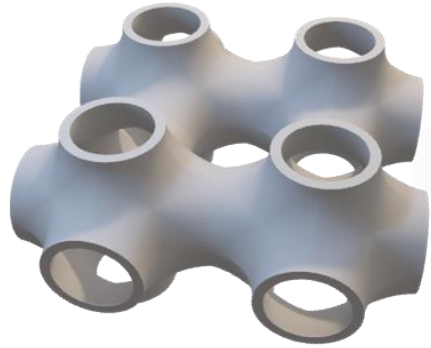


2 layers

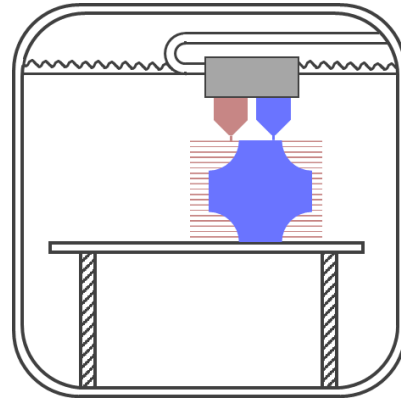
SUMMARY



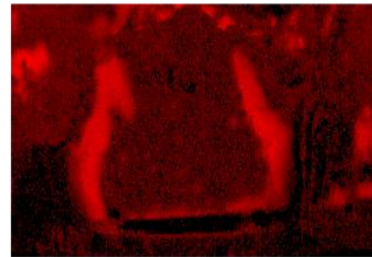
Schwarz primitive surface



3D printing

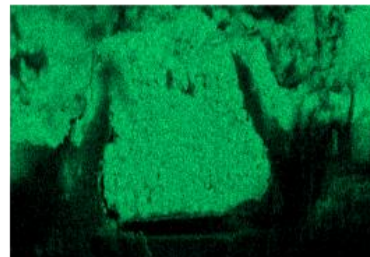


C K α 1,2



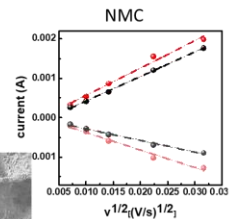
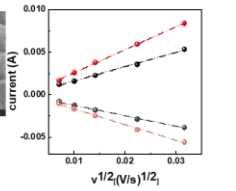
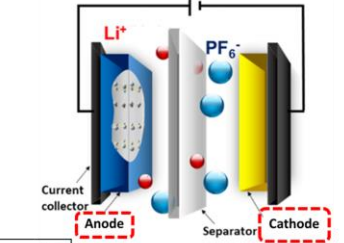
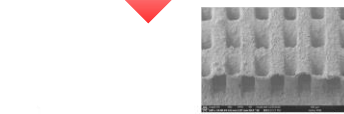
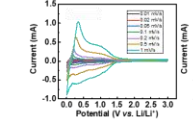
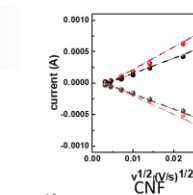
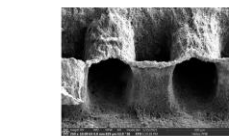
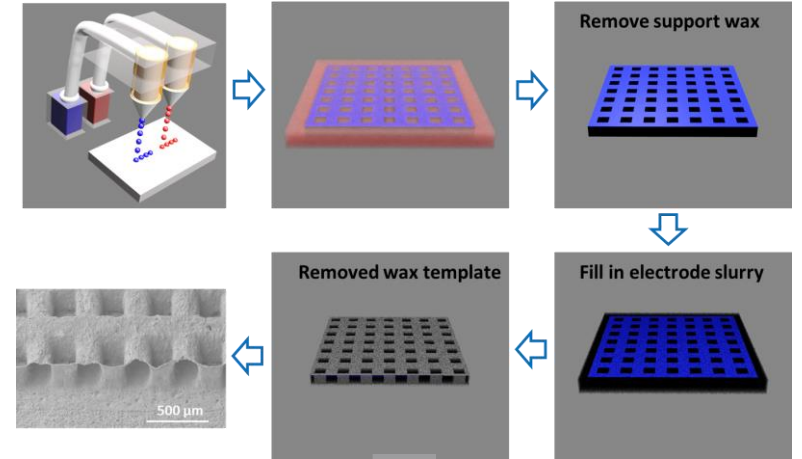
100 μ m

P K α 1



100 μ m

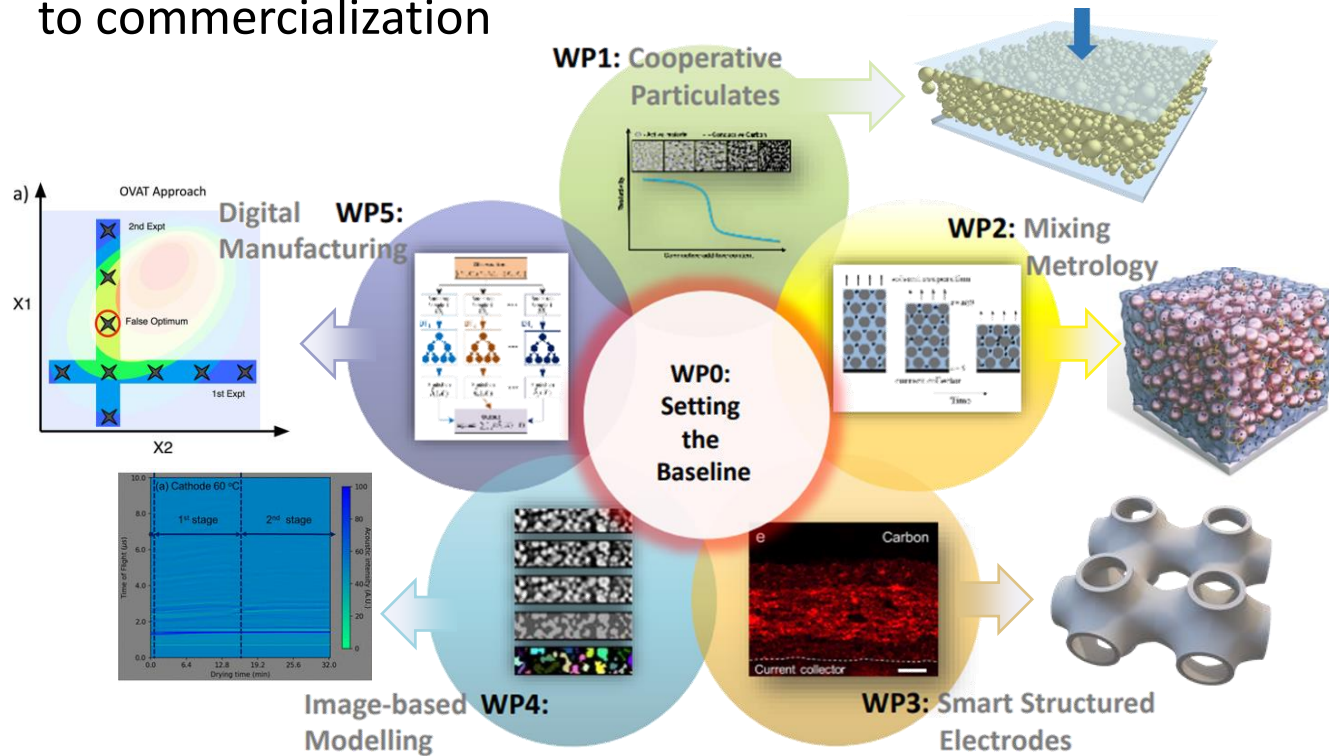
print the reverse structure as a wax template



Thank you! More information on NEXTRODE project:



➤ The Faraday Institution project- NEXTRODE:
aiming to research new methods for manufacturing smarter electrodes and to put them onto the path
to commercialization



- **WP1: Denis Cumming (1st Nov. 15:55)**
Ruihuan Ge (2nd Nov. 12:30)
- **WP2 and WP4: Yeshui Zhang (poster)**
ACS Appl. Mater. Interfaces 2021, 13, 30, 36605–36620
- **WP3: Yige Sun (1st Nov. 14:50)**
- **WP5: Geanina Apachitei (2nd Nov. 15:35)**



Thank you

Questions and comments are welcomed



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www.nextrode.web.ox.ac.uk