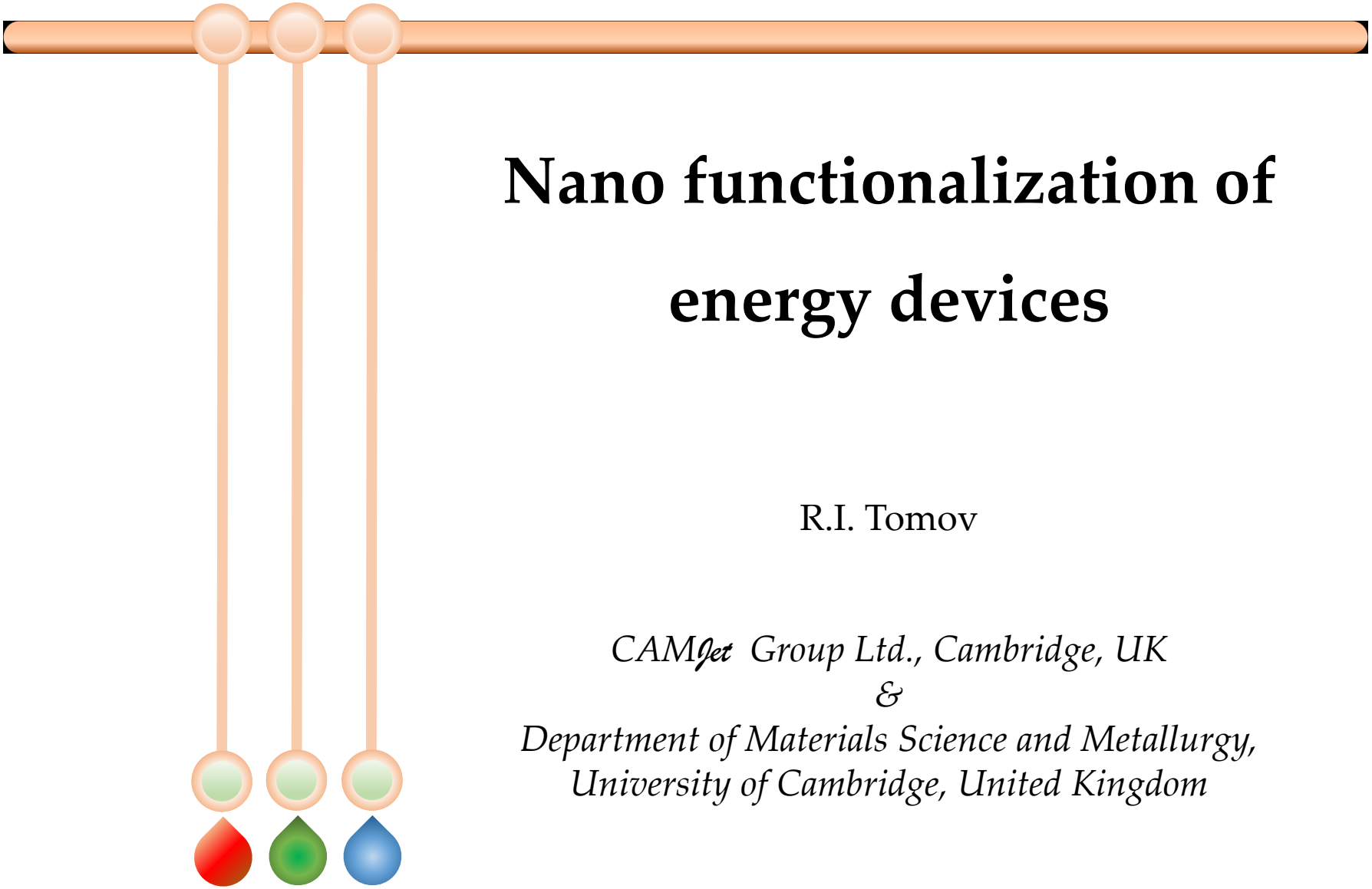
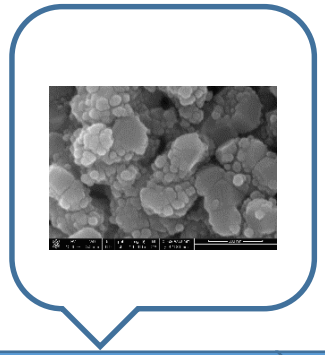


Nano functionalization of energy devices

R.I. Tomov

CAMJet Group Ltd., Cambridge, UK
&
Department of Materials Science and Metallurgy, University of Cambridge, United Kingdom



Motivation

Problems and Solutions

3D case study

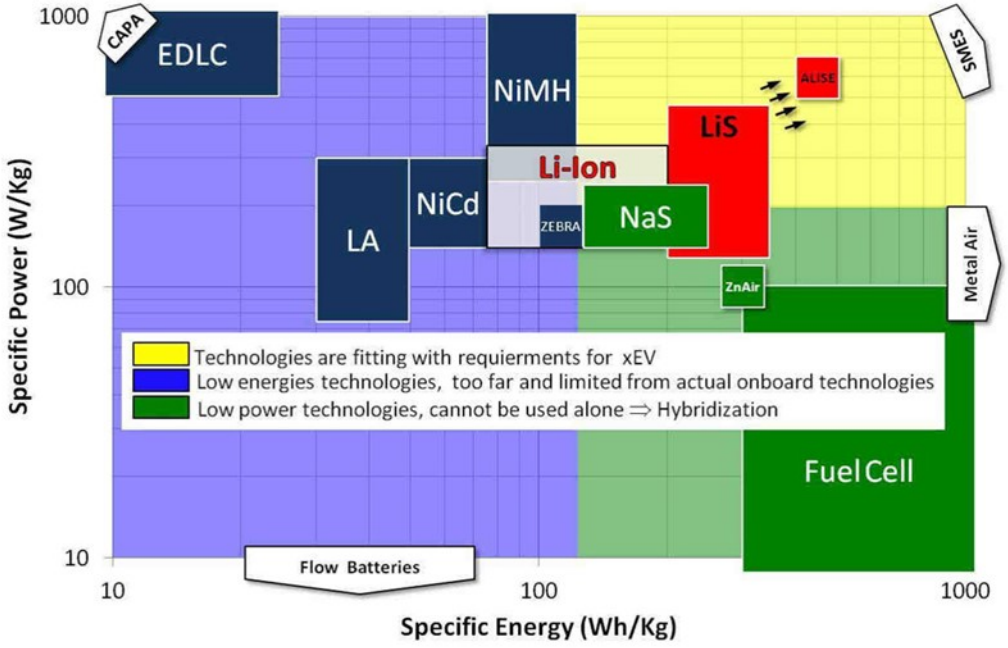
2D case study

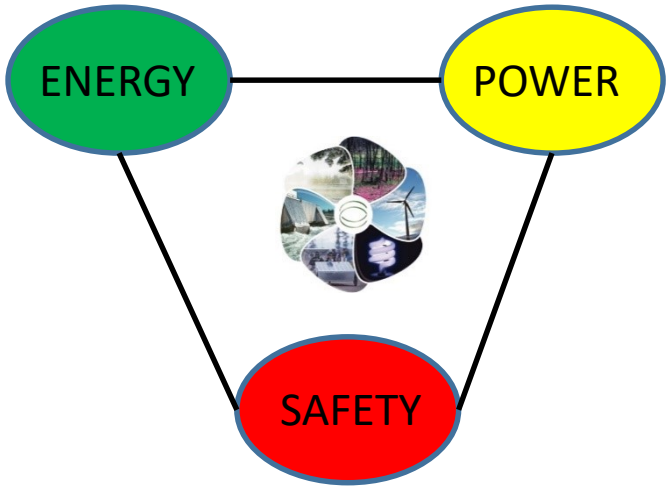
Global Drivers

- **Environmental changes** - demand for alternative energy sources for the new economy.
  - *Climate change issues; globalization - new government regulations, labor migration, emerging technologies, socio-economic factors, geo-political implication, global financial instability.*
  - *An average coal-fired power plant emits ~ 100 kg of arsenic, 500 tons of particulates, four pounds of cadmium, 5,000 tons of sulfur oxides, 50 kgof lead, one million tons of carbon and 10,000 tons of nitrogen oxides annually.*
- **Constantly rising demand for oil** primarily driven by the developing world's consumption, which is rising three times as fast as in the OECD.

Global Solutions

- **Popular higher rate-of-return alternative energy sources such as: wind and solar cell.**
- **Storing this energy is one of the greatest barriers to the adoption of renewable energy.**
- **Complimentary use of hydrogen (fuel cells and electrolysers) and battery storage is the key to success (**EU "Directive on Deployment of alternative fuels Infrastructure" **).**

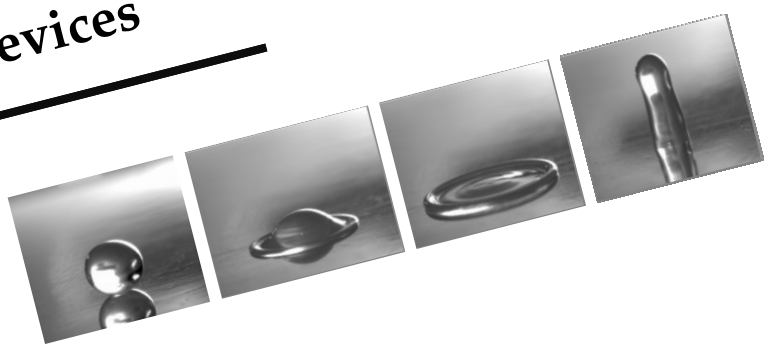


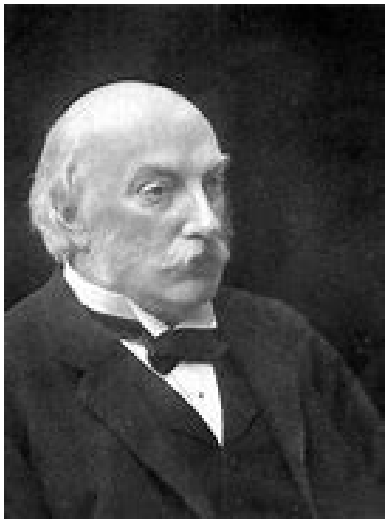


http://www.aliseproject.com/li-s-batteries/

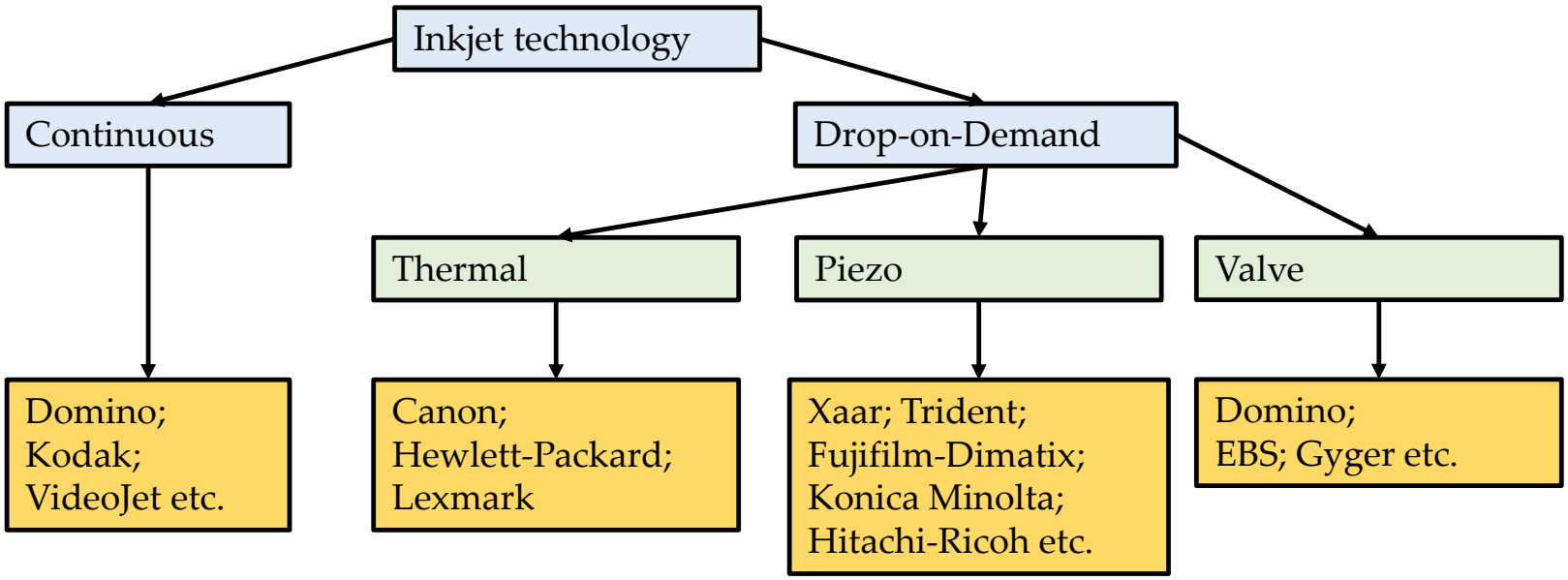
INKJET PRINTING

A tool for nano-functionalization of energy devices





In 1878 Lord Rayleigh studied the breakup of droplets when a pressure wave was applied. However, it was only in 1960 that Richard G. Sweet fabricated printed equipment based on these previous discovered principles.



Why inkjet?

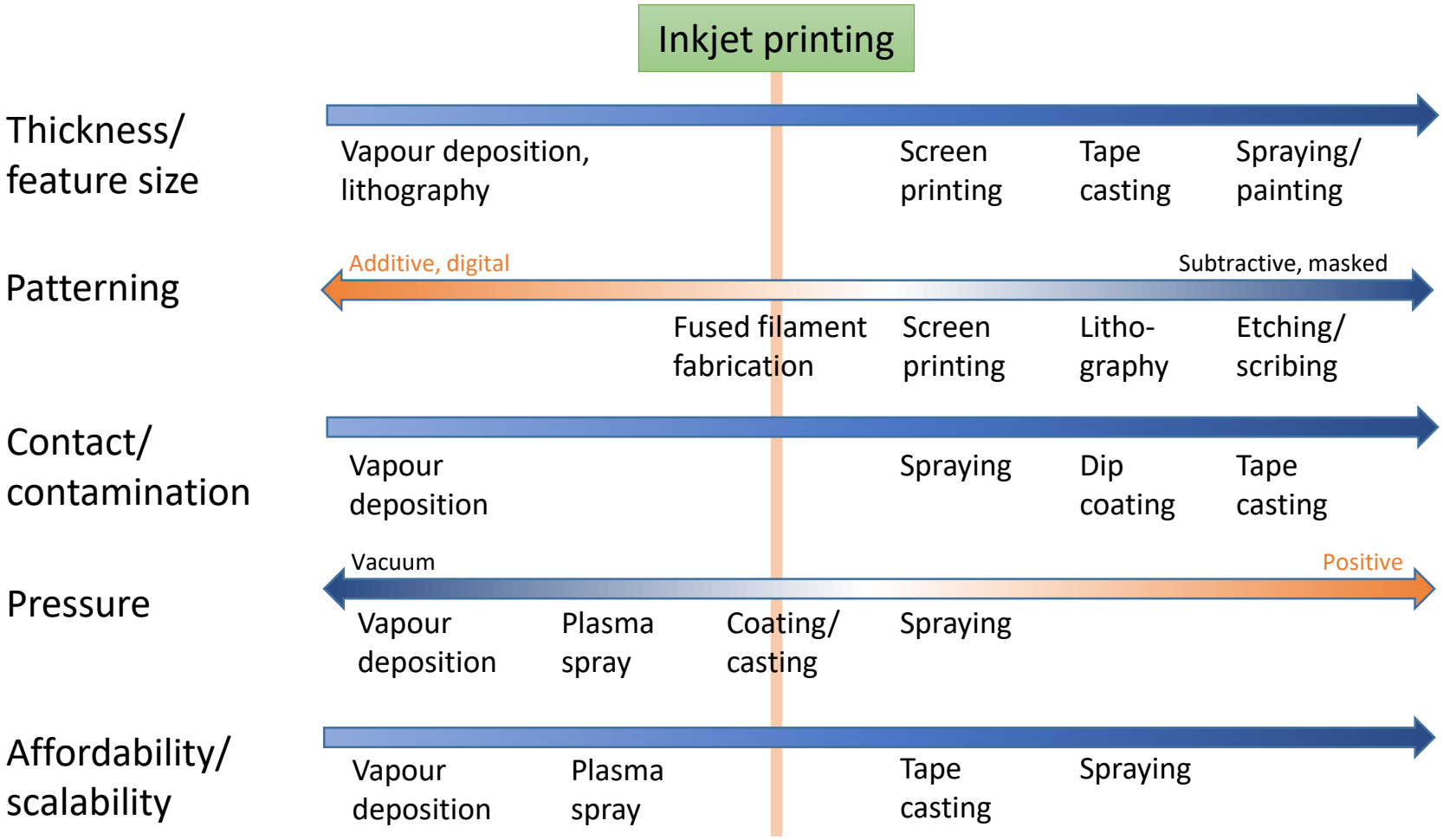
Non- contact - Deposition on fragile or 3D structured surfaces

Digital control - Flexible pattern deposition. 3D functionalization.

Functional materials - Organic, inorganic, biomaterials.
Solutions, suspensions, colloids, emulsions, melts.

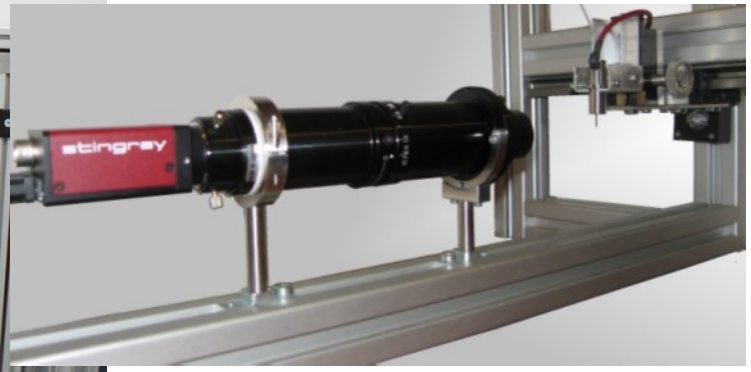
Reduced production cost - Efficient use of precursors.
Additive processing.

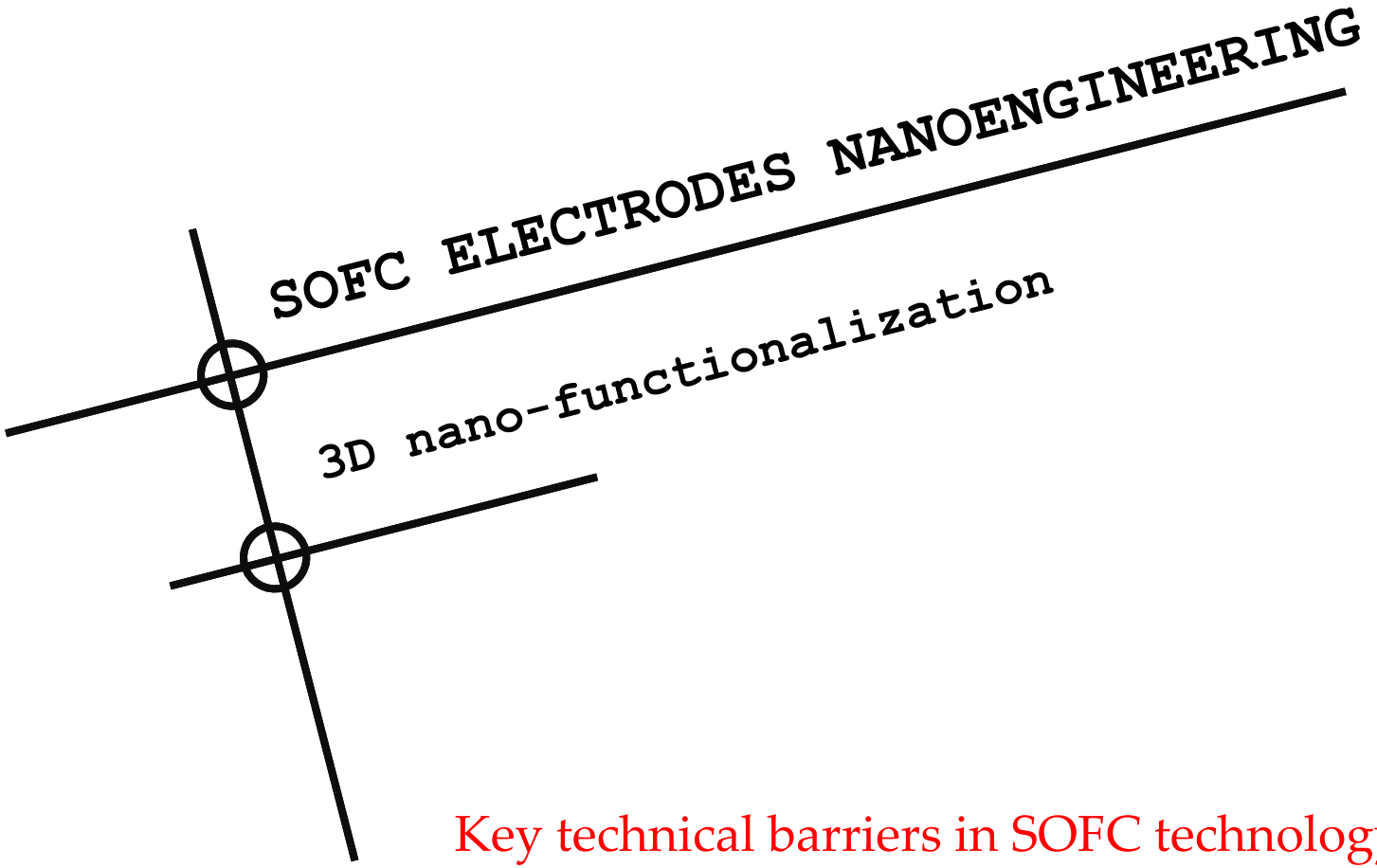
Increased throughput - High frequency printing.
Quick set-up. Easy customization.


Inkjet printing
Thickness/ feature size
Vapour deposition, lithography
Screen printing
Tape casting
Spraying/ painting
Patterning
Additive, digital
Subtractive, masked
Fused filament fabrication
Screen printing
Litho-graphy
Etching/ scribing
Contact/ contamination
Vapour deposition
Spraying
Dip coating
Tape casting
Pressure
Vacuum
Positive
Vapour deposition
Plasma spray
Coating/ casting
Spraying
Affordability/ scalability
Vapour deposition
Plasma spray
Tape casting
Spraying

Cjet **printer**

- Bespoke inkjet printing equipment and software developed, designed for materials applications
  - Interchangeable print-heads and inkjet printing technologies
  - Integrated drop visualisation
  - Robust and affordable



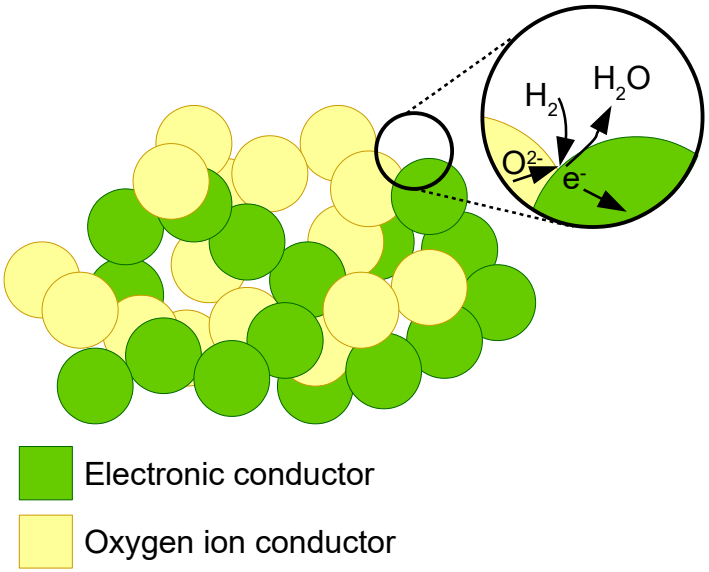


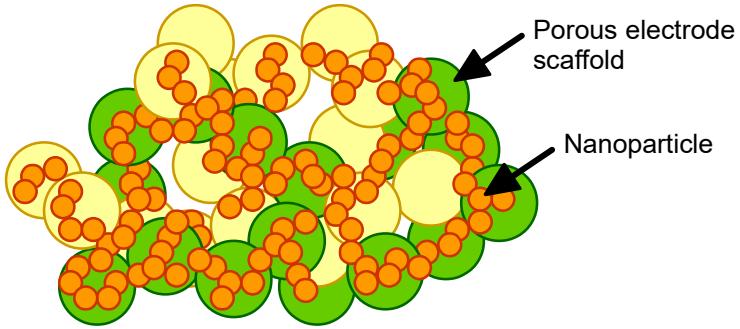
Key technical barriers in SOFC technology
(i) insufficient thermal resistance,
(ii) insufficient overall energy efficiency of SOFC stacks,
(iii) insufficient lifetime utilisation.

Solid oxide fuel cells – infiltration nano-engineering

- Nanostructuring the porous electrode: reduce R_p, increase TPB & power output and improve long term stability

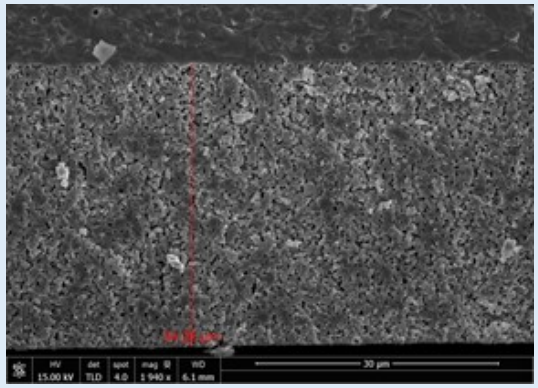
- Solution infiltration via inkjet printing

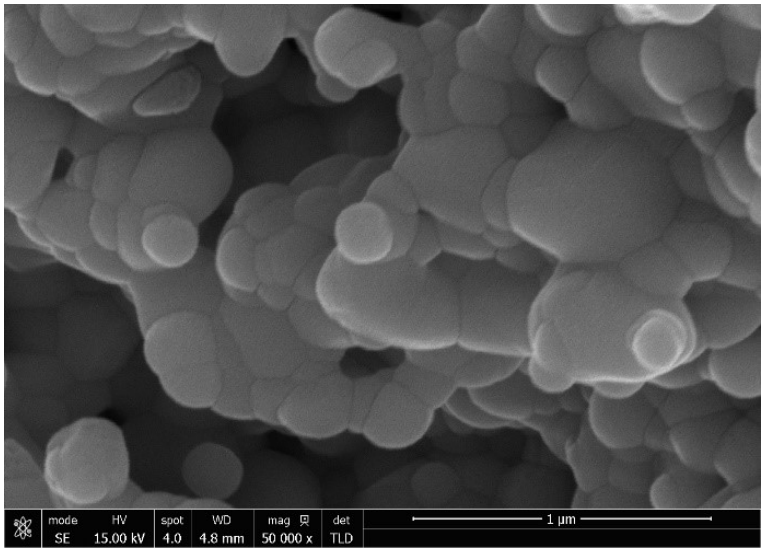


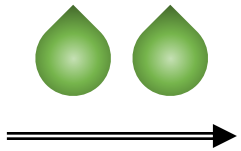


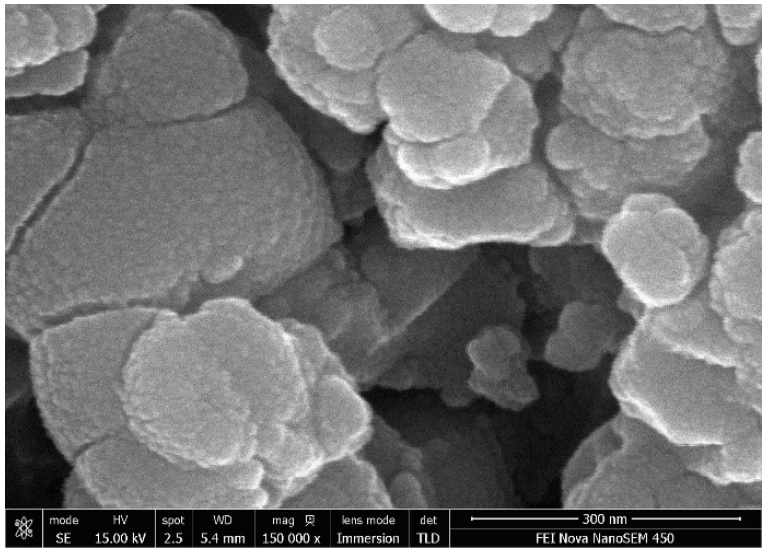
SOFC cathode infiltration

- Cathode: $La_{0.6}Sr_{0.4}Co_{0.2}Fe_{0.8}O_3/Ce_{0.9}Gd_{0.1}O_2$ composite
- Electrolyte: $Ce_{0.9}Gd_{0.1}O_2$
- Infiltrated with Co_3O_4 and Gd:doped CeO_2









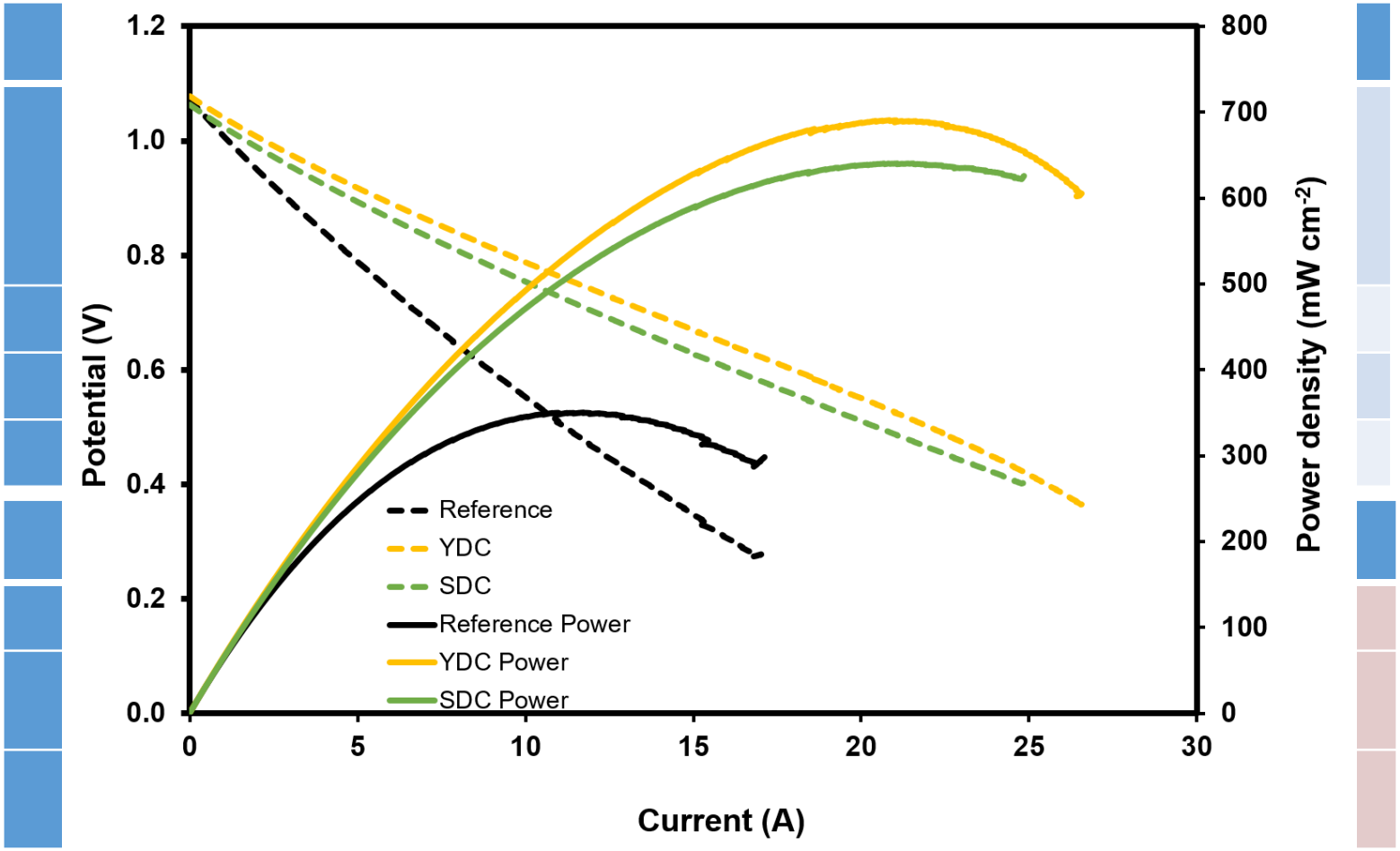
Nano-structuring objectives

- *Enhancement* of electrochemical performance by extension of TBP / density of active catalytic sites via nano-decoration (discrete nano particles or complete coating)
- *Low temperature calcination* of infiltrated materials
- *Avoidance* of detrimental interactions
- *Minimizing* the effect on concentration polarization losses
- *Long term stability* of the performance improvement

- **Low cost scalable technology**

ASR values and Degradation rate

Aging for 100 hours at 650 °C; testing at 650°C in air



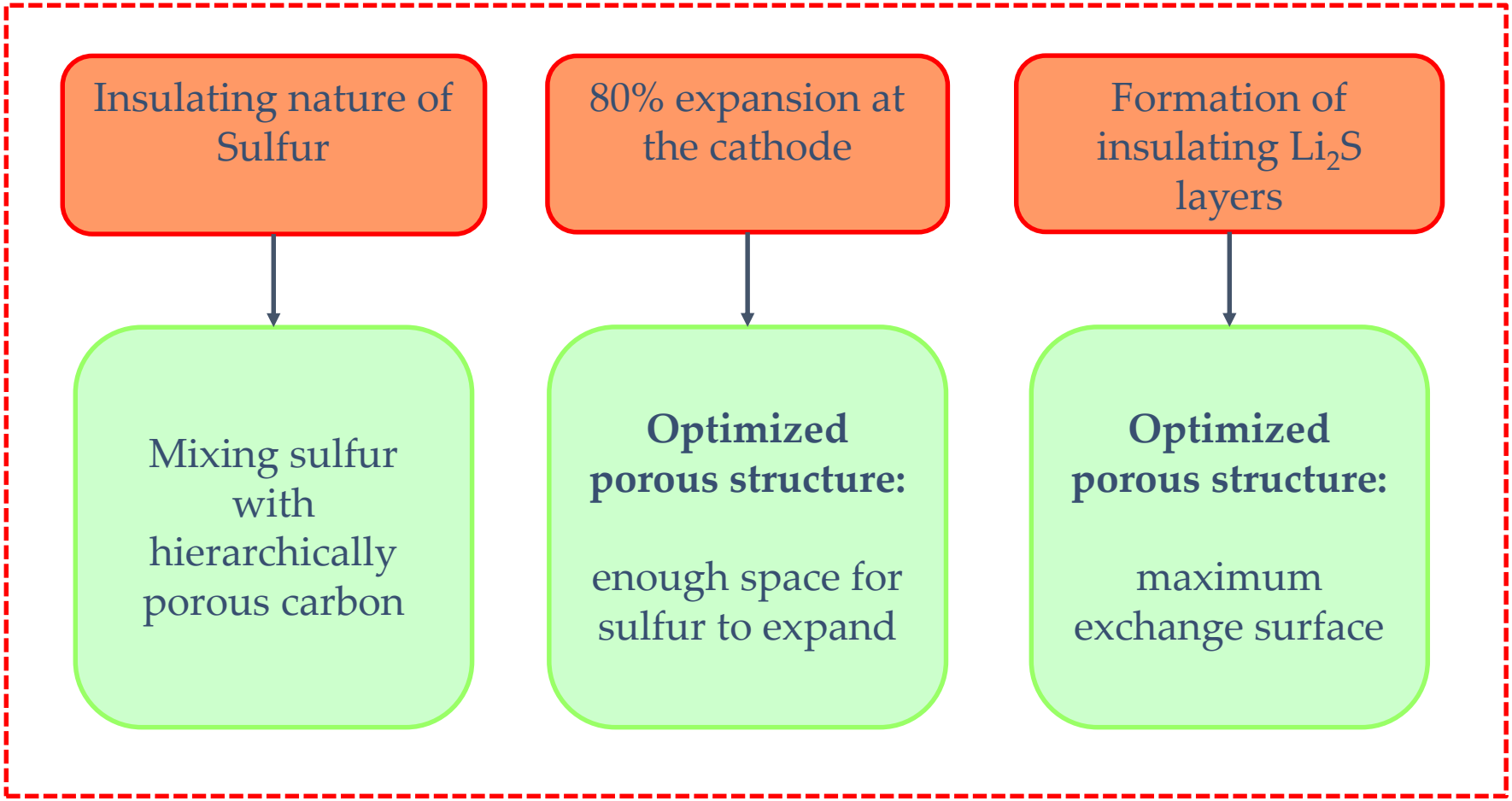
Inkjet-printed LiS battery cathode

3D functionalization

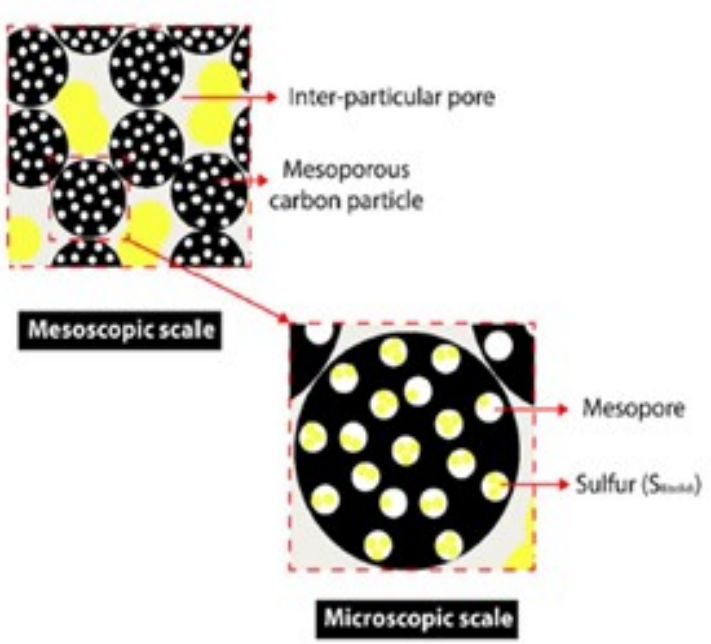
The Zephyr 7 holds the official endurance record for an unrefueled flight, lasting 336 hours, 22 minutes and 8 seconds. It uses sunlight to charge a lithium-sulfur battery during the day.

Lithium-Sulfur batteries

- High theoretical capacity – 1672 mAh/g !
- Sulfur is inexpensive and abundant !



Inkjet-printed LiS battery cathode

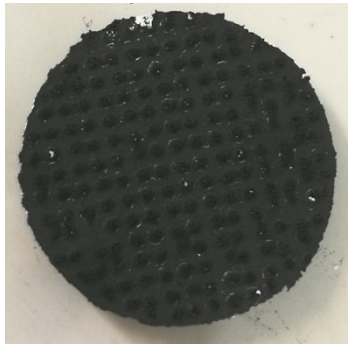


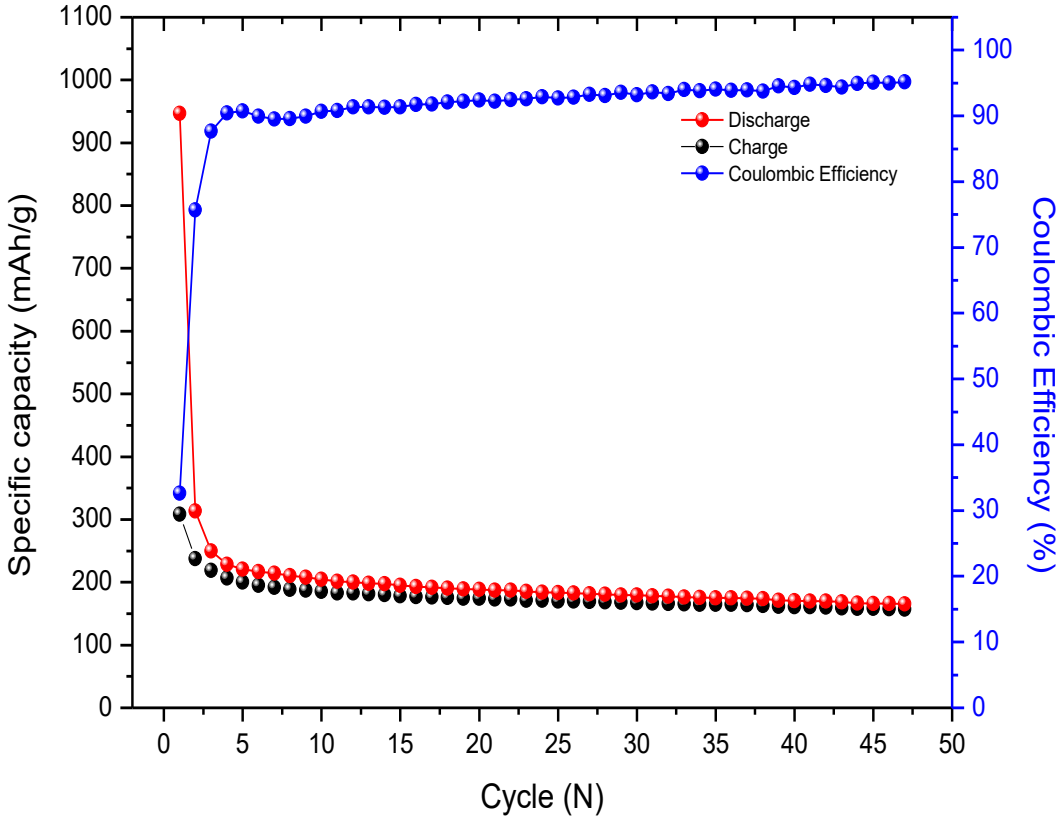
Substrate porosity

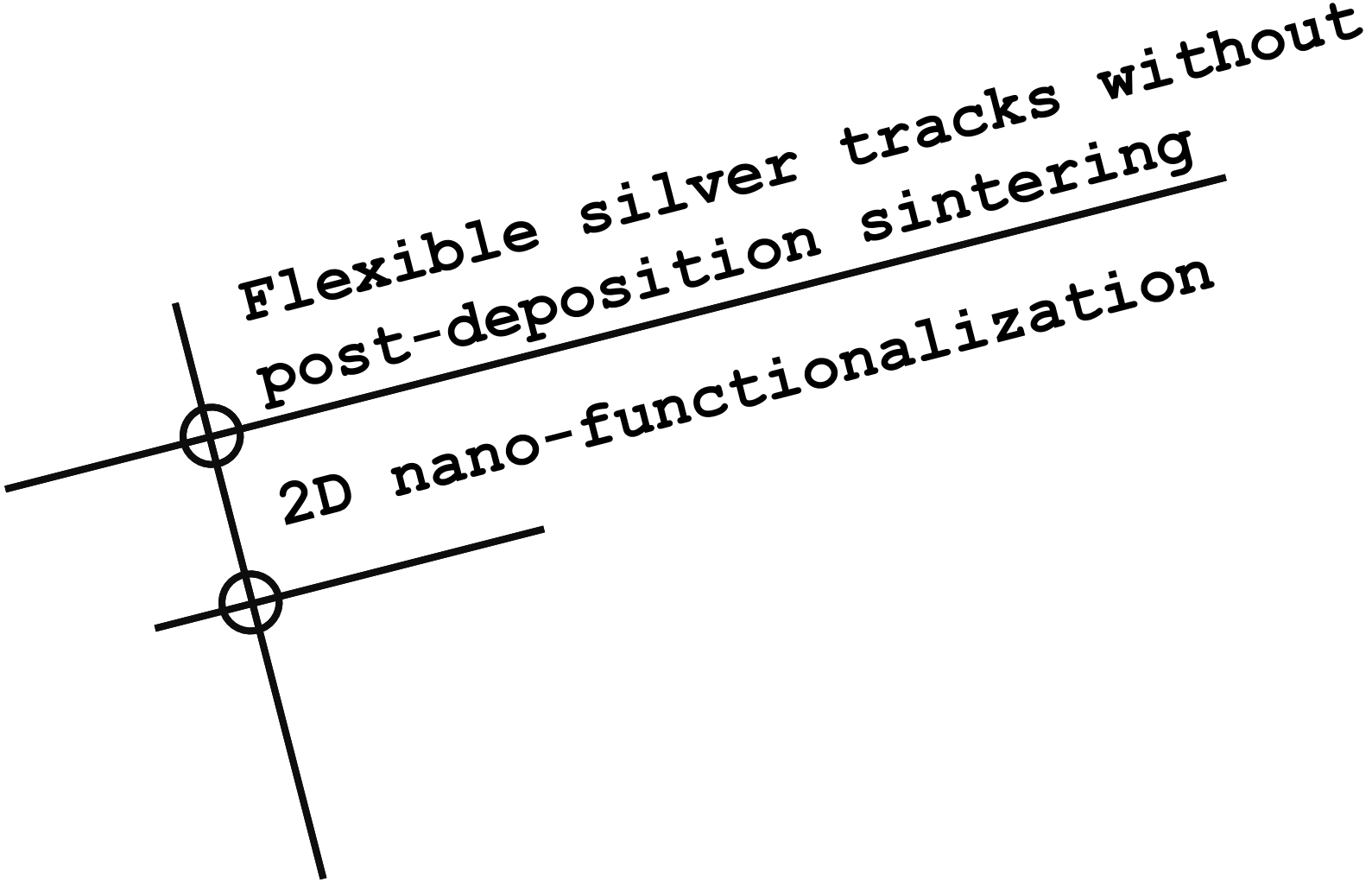
Micropores: 1-3 nm
Mesopores: 3-10 nm
Inter-particular pores: > 30 nm

Fiber diameter: 1000 nm

Inkjet-printed LiS battery cathode

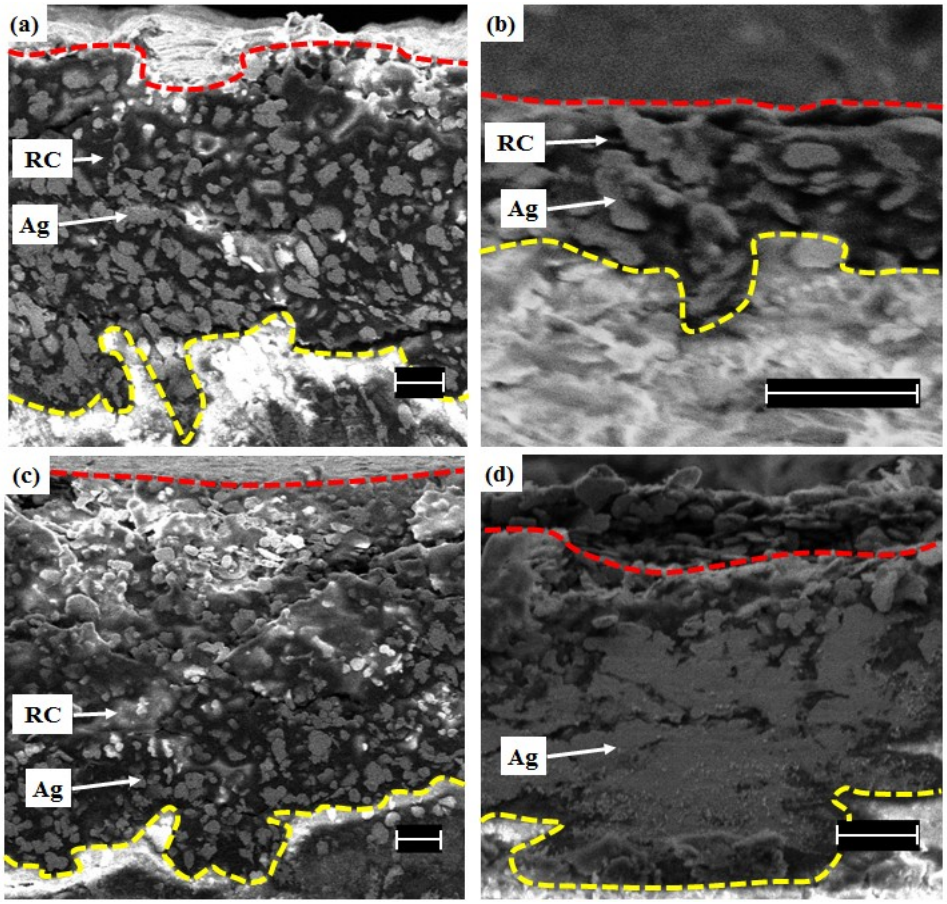






Temperature sensitive substrates cannot withstand sintering of high temperature !

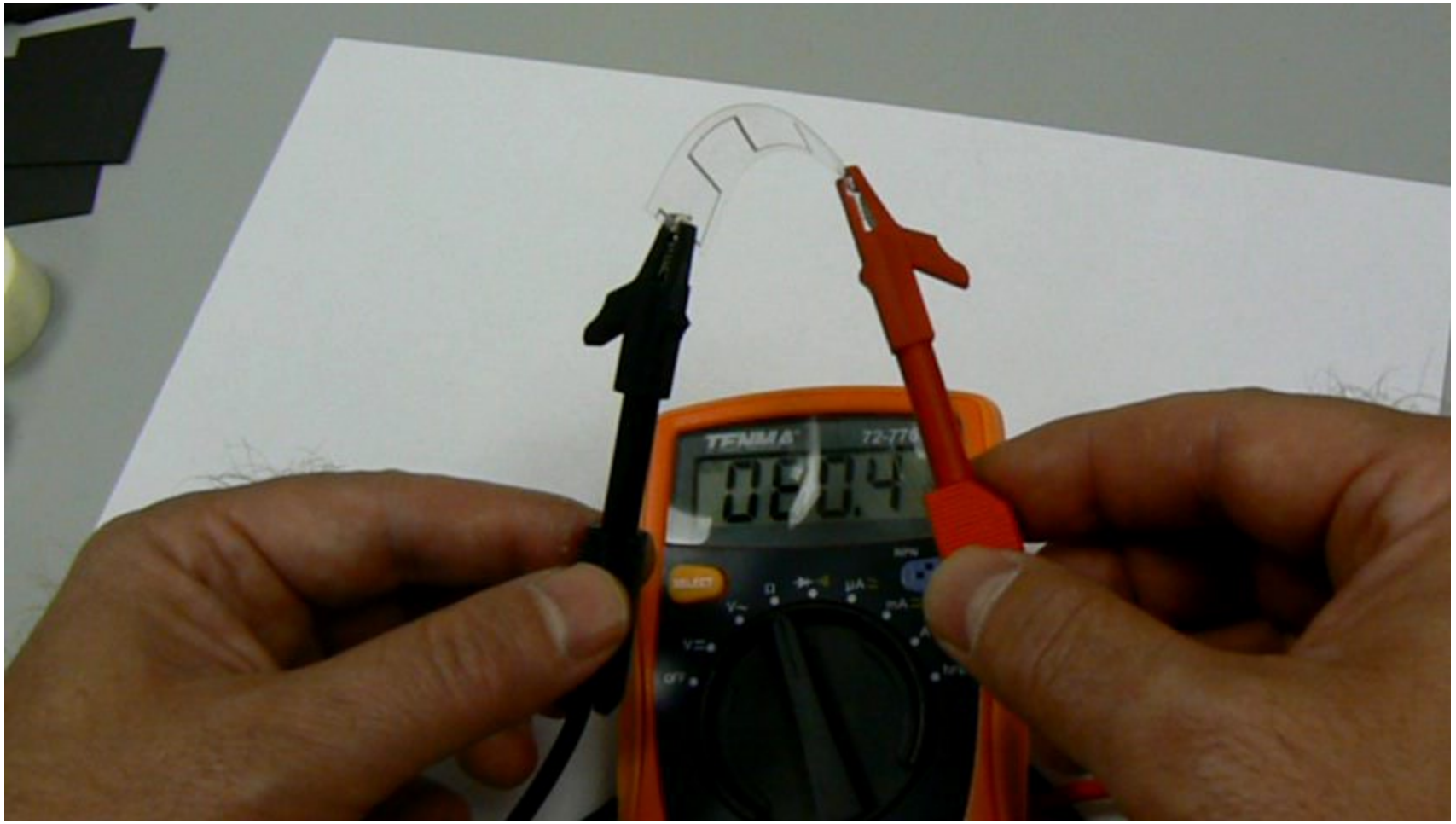
Conductive tracks for flexible electronics



(a) doctor blading
(b) flexography of the as-received ink,
(c) doctor blading of a thinned ink (40% ink and 60% water)
(d) inkjet printing of a thinned ink (40% ink and 60% water).

(The dotted lines show layers with a thickness of (a) 27μm, (b) 7 μm, (c) 38 μm and (d) 19 μm, respectively)

Aqueous-based silver ink (DZP Technologies Ltd, UK - silver flakes (90% < 3.9 μm)


TENMA
SELECT

Summary

- Inkjet printing nano-functionalization method has been successfully applied in several functional energy materials applications.
- *CAMJet* Group Ltd. was created with an ambition to commercialize the technology.
- The company aims to provide a flexible platform for inkjet processing for a variety of customers – academic institutions, R&D sector, ink developers etc.

Thank you for your attention !