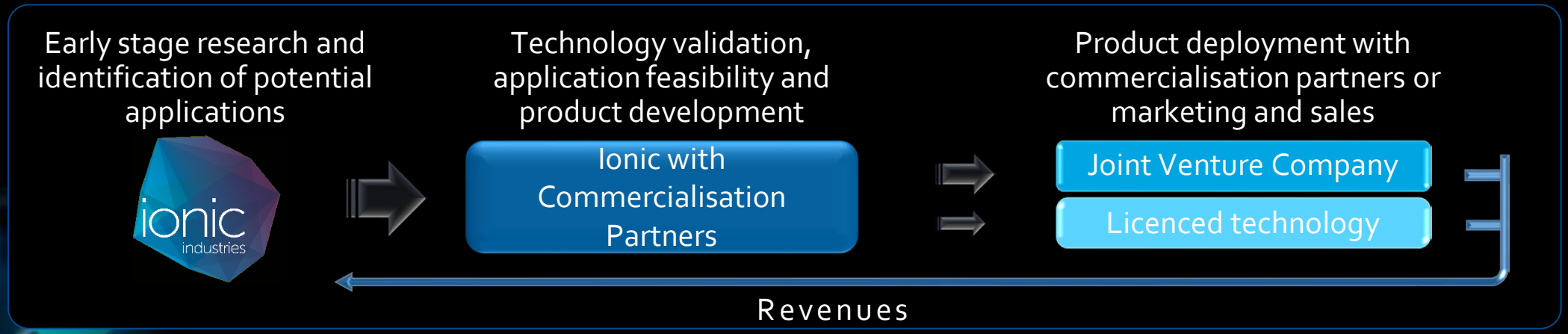
ionic
industries

MICRENs – Next Generation Energy Storage

GRAPHENE PLANAR MICRO SUPERCAPACITORS FOR LOW VOLUME, HIGH ENERGY APPLICATIONS

Who is Ionic?

A collaboration-based, technology platform delivering a consistent flow of advanced materials technology from lab to market, addressing the world's biggest problems

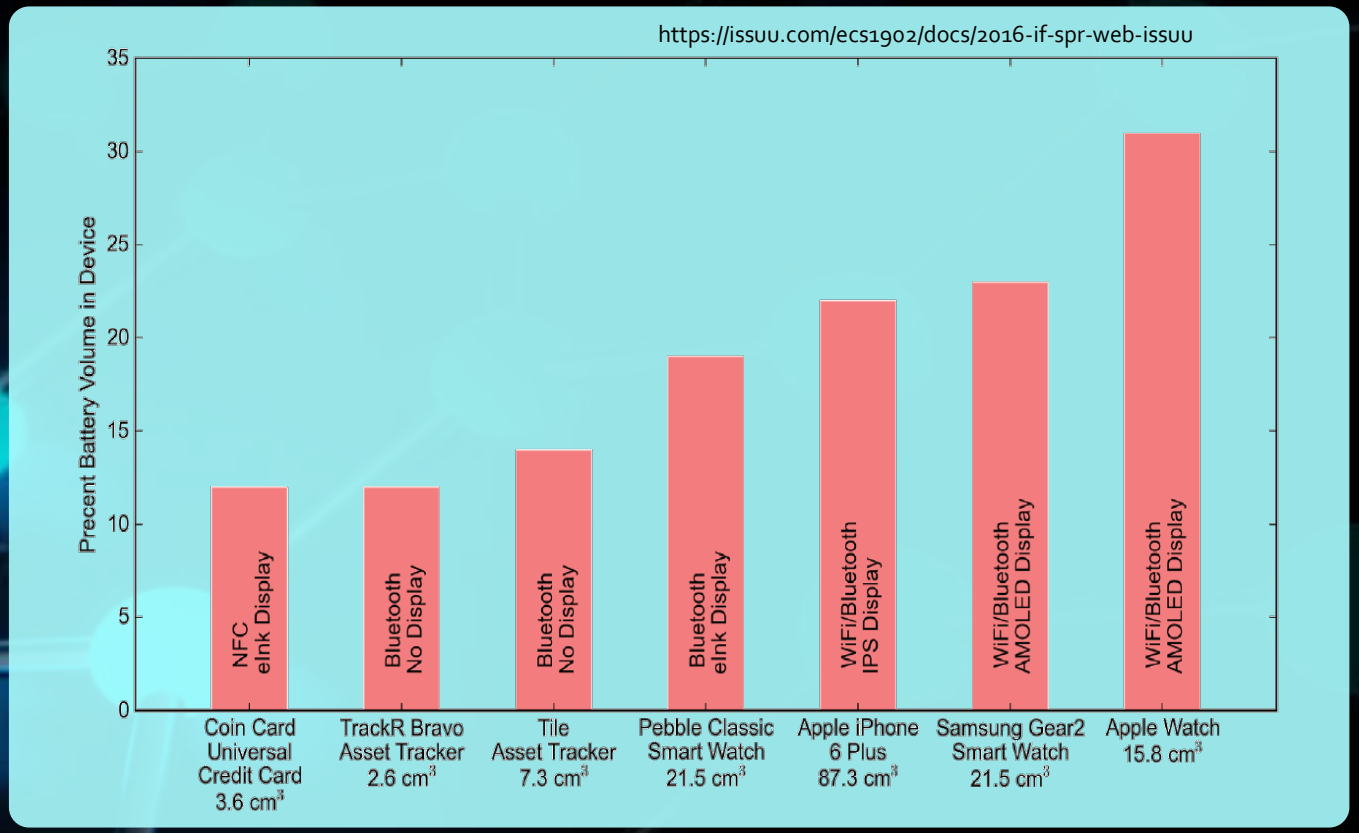


- Building on our partnerships and technology over 7 years and $3.4 million in R&D funding, Ionic is amongst the first companies working on commercially viable applications of graphene technologies
- Collaboration model reduces technology validation risks and accelerates paths to market, thereby reducing uncertainty and business risks
- Portfolio approach to technologies and applications mitigates the risk of reliance on a single technology and expands market potential

Ionic Industries MICRENs

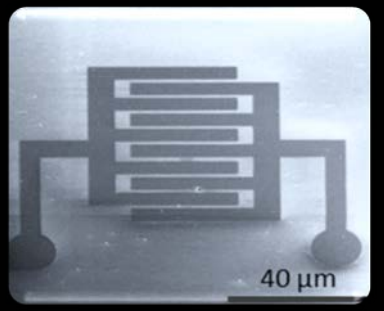
Energy storage technologies are one of the greatest constraints in the development of many new technologies.

Small portable electronic devices have steadily evolved toward compact and thin form factors and batteries have become an ever-increasing fraction of the total device volume.



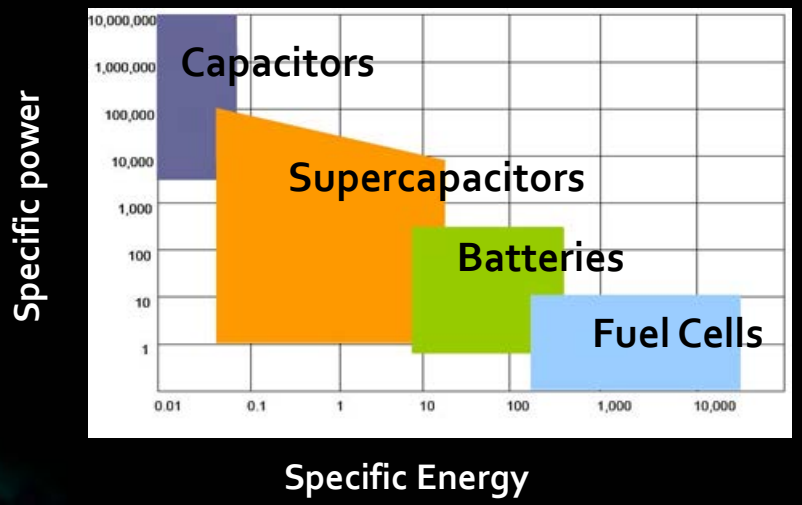
Requirements to both store energy AND discharge / recharge at a rapid rate are holding back applications in a wide range of fields from consumer electronics, medical and health devices and IoT markets.

MICRENs devices represent next generation energy storage technology – supercapacitors with as much energy as lithium ion batteries.



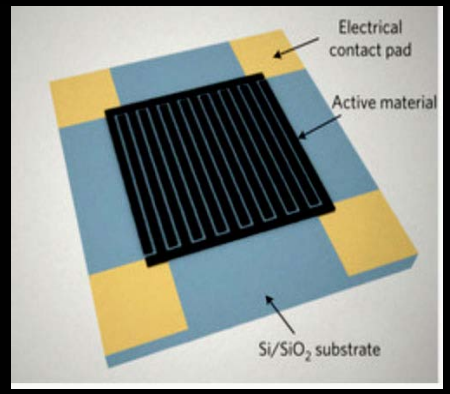
Why Supercapacitors?

http://www.cap-xx.com/resource/energy-storage-technologies/



- Offer balance in energy and power requirements in portable electronics
- High charge / discharge efficiency
- Green technology
- Minimal maintenance

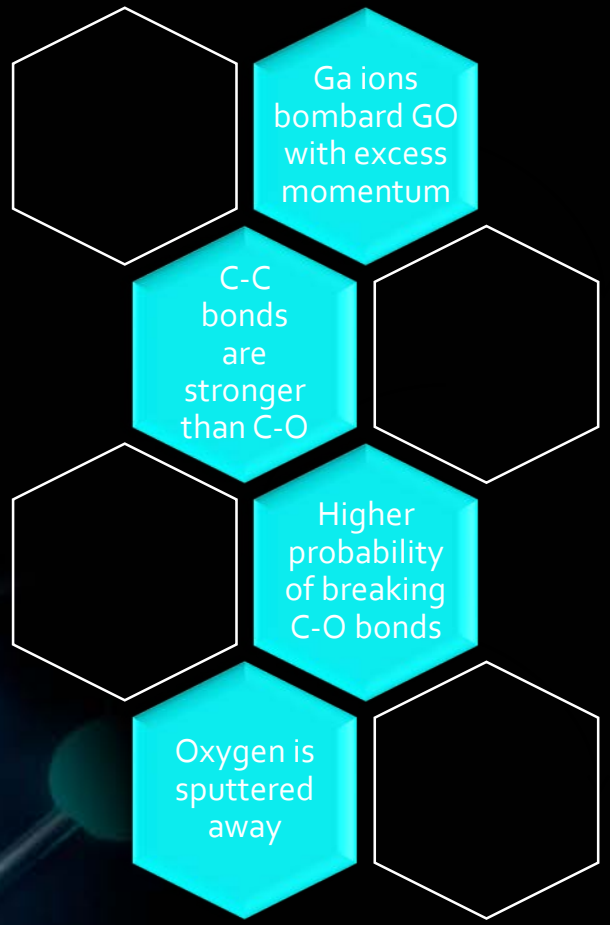
Planar supercapacitors have a number of advantages over conventional 3D supercapacitors

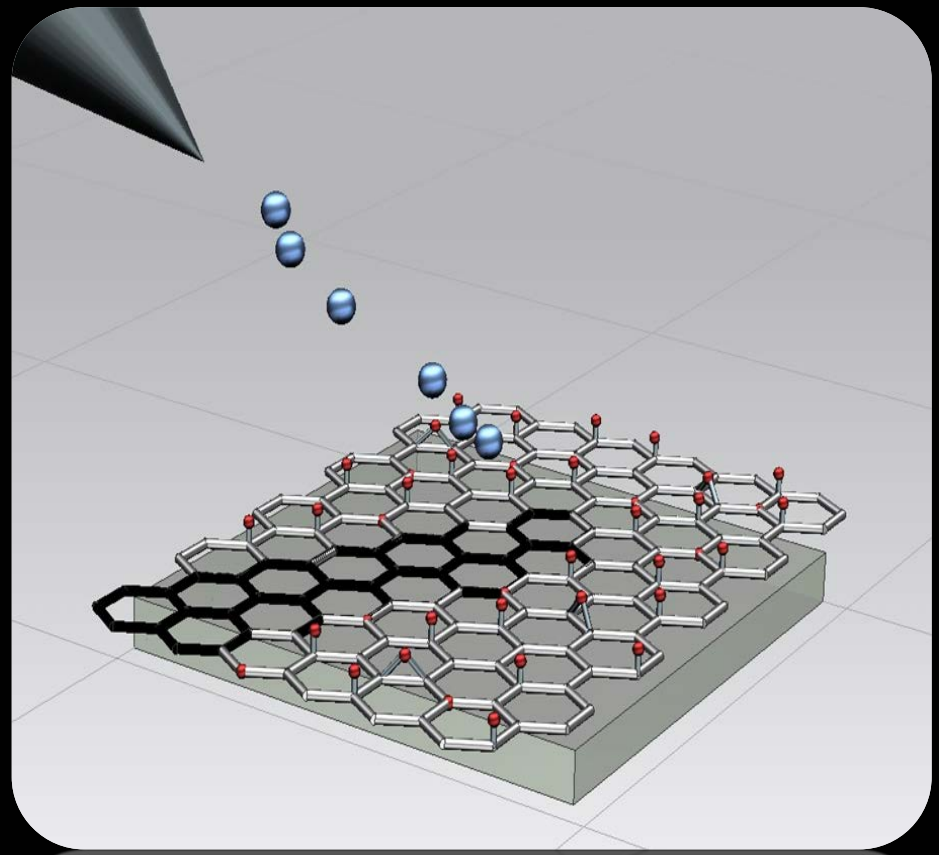


El Kady *et al*, *Science*, 2012, 335, 1326-1330
Pech *et al*, Nature Nanotechnology, 2010, 5, 651-654

- Control and shorten the distance ions travel between the two electrodes
- Easily integrated into devices
- Potentially the architecture can be extended in 3D without losing the inter-electrode distance

Our approach

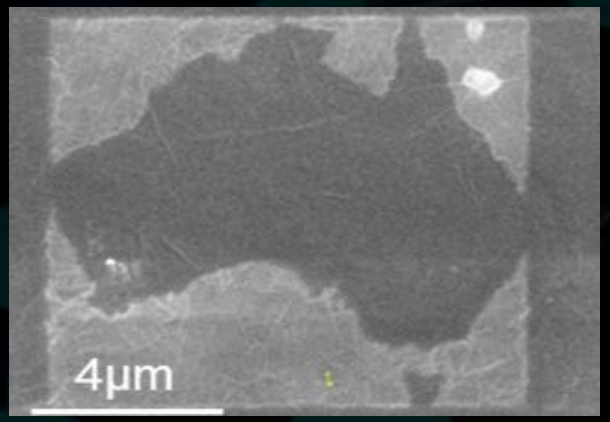


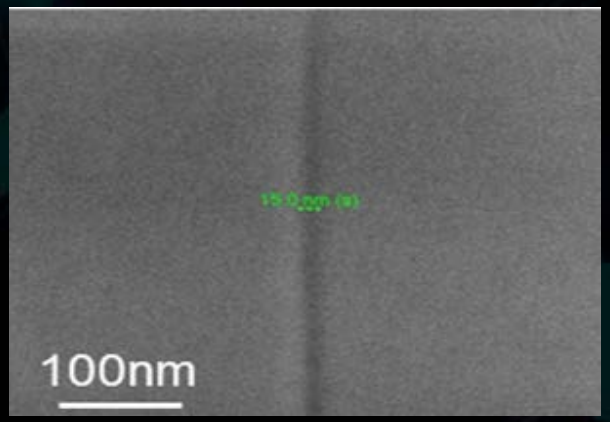


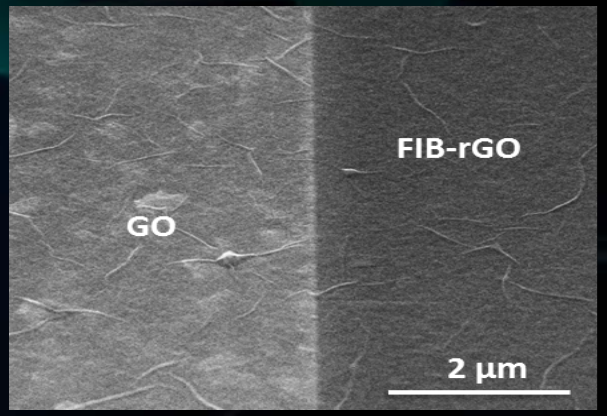
Lobo *et al*, *Langmuir*, 2012, 28, 14815-14821

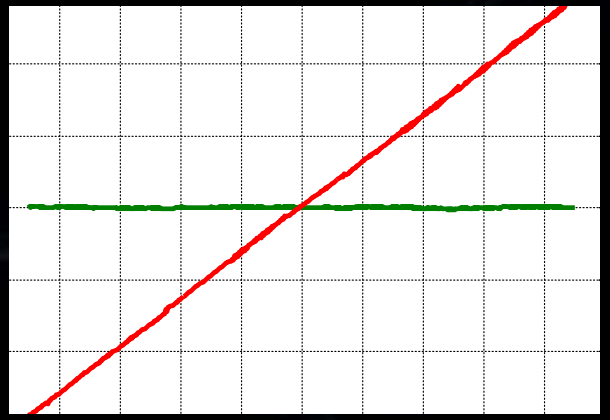
Advantages of our approach

Fast direct-write method, Fine feature control, Minimal damage of GO sheets







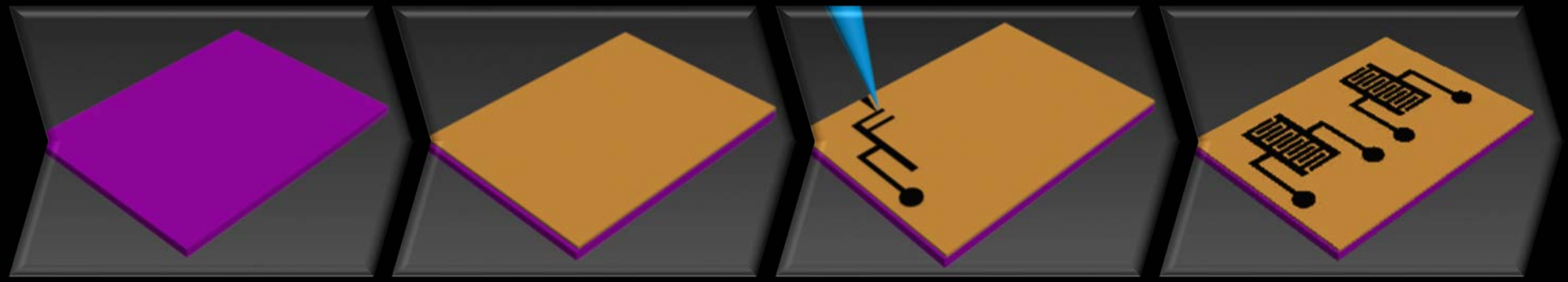


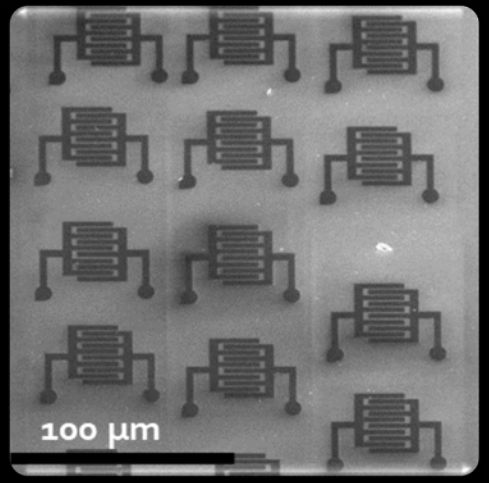
Lobo *et al*, *Langmuir*, 2012, 28, 14815-14821

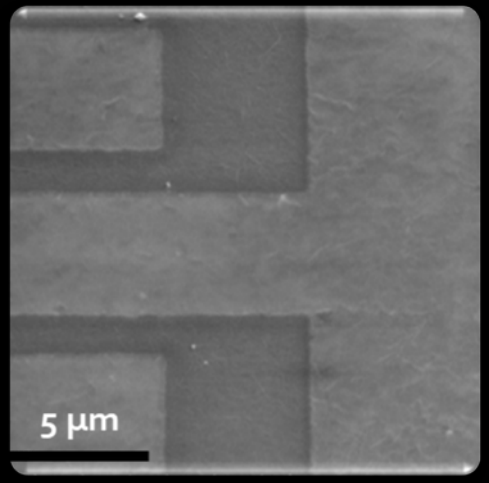
Majumder *et al*, US9558887B2 (grant)

Fabrication of the FIB rGO electrodes

Fabrication of the FIB electrodes is a simple, 3-step process.

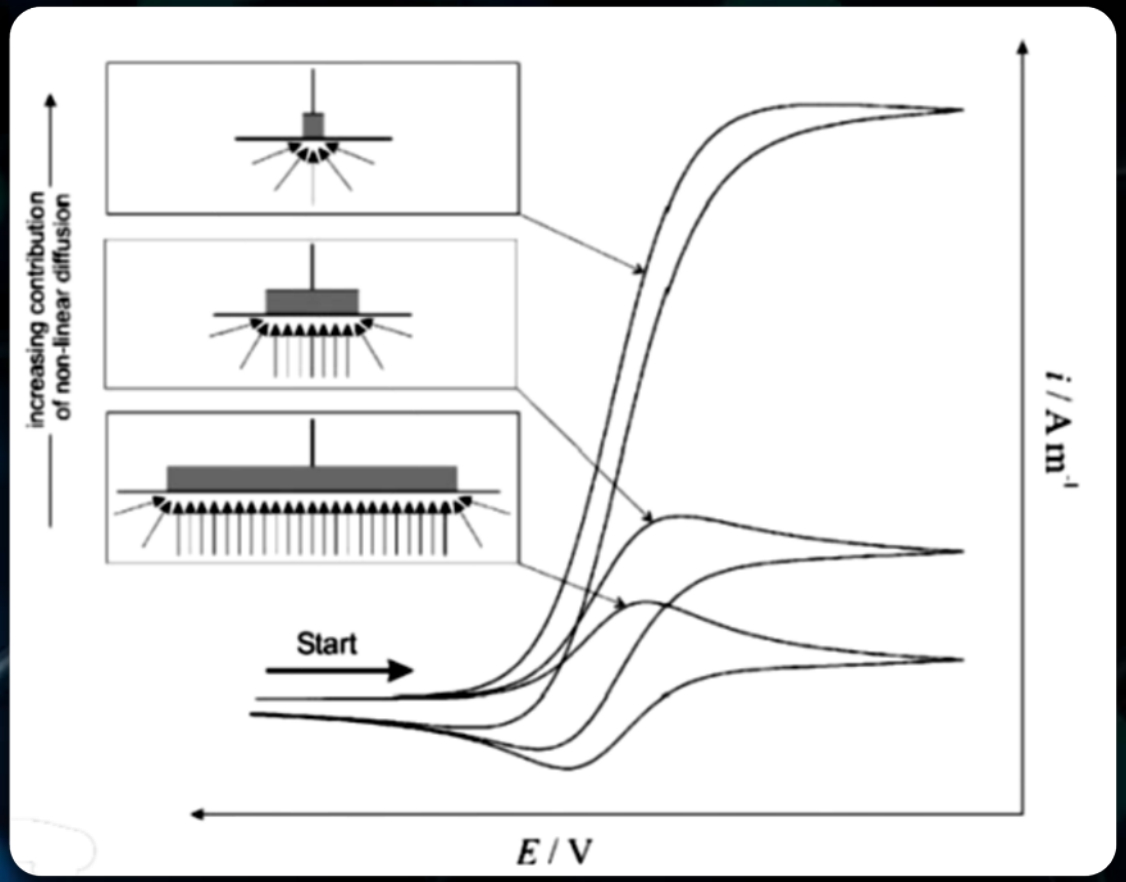






Why Miniaturize?

Miniaturization ➔ Enhanced electrochemical response



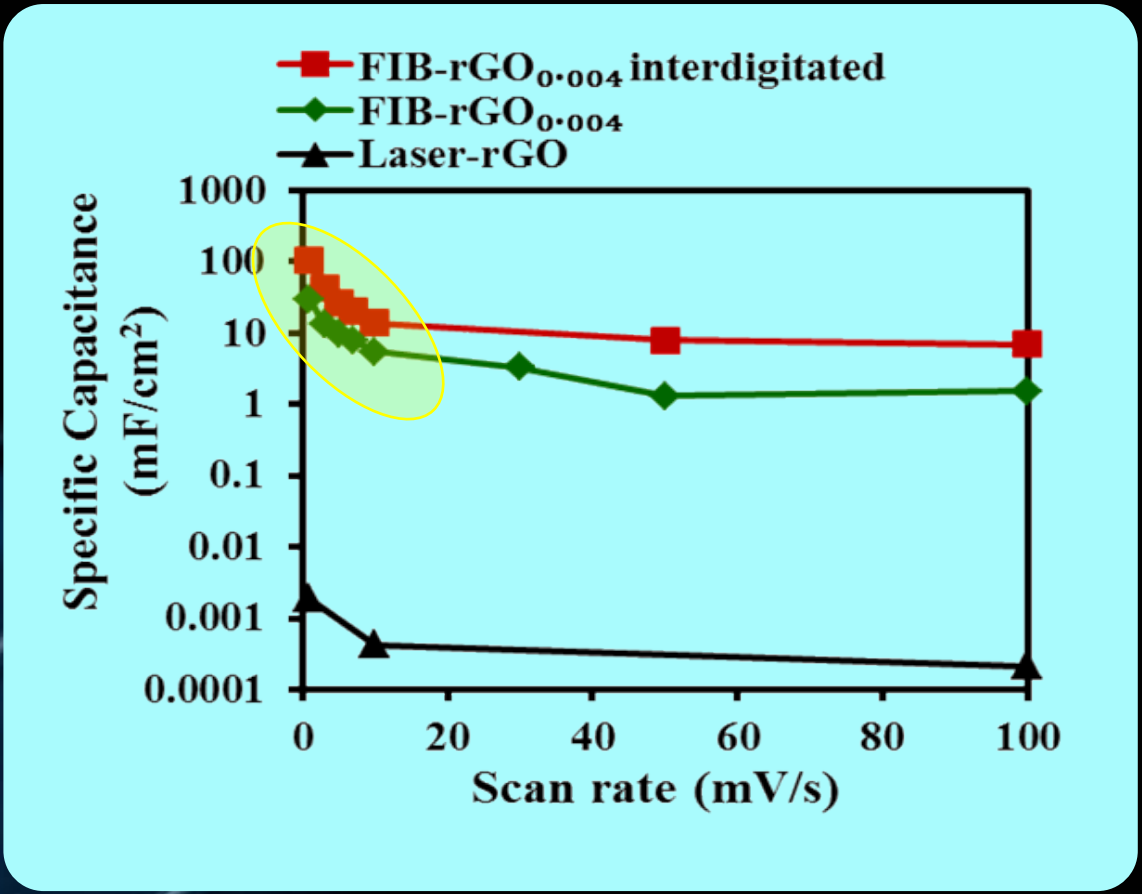
F. Marken, A. Neudeck, A. M Bond, Electroanalytical Methods (Ed. F. Scholz), Springer, 2010

$$I_F = nFAC_{\propto}^{0}\left(\frac{D_0}{\pi t}\right)^{\frac{1}{2}}$$

For microelectrodes,

$$I_F = nFAC_{\propto}^{0}\left(\frac{D_0}{\pi t}\right)^{\frac{1}{2}} + nFAD_0\frac{C_{\propto}^{0}}{r}$$

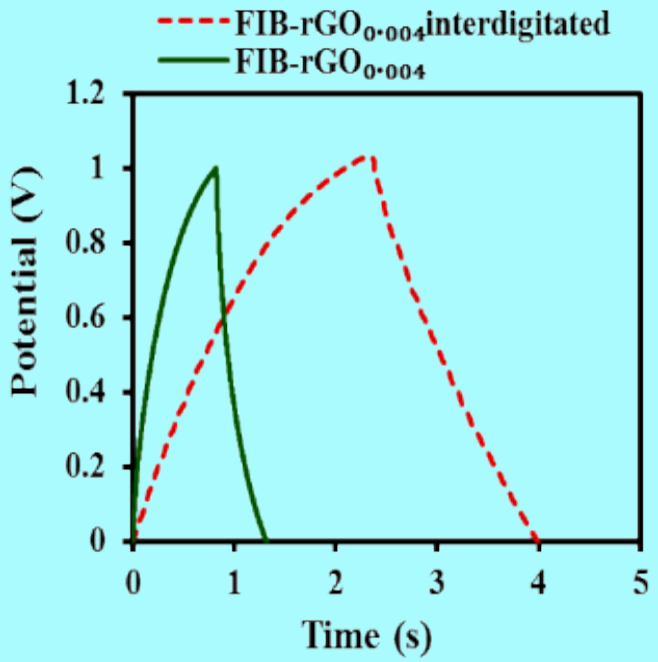
Capacitance vs Scan Rate

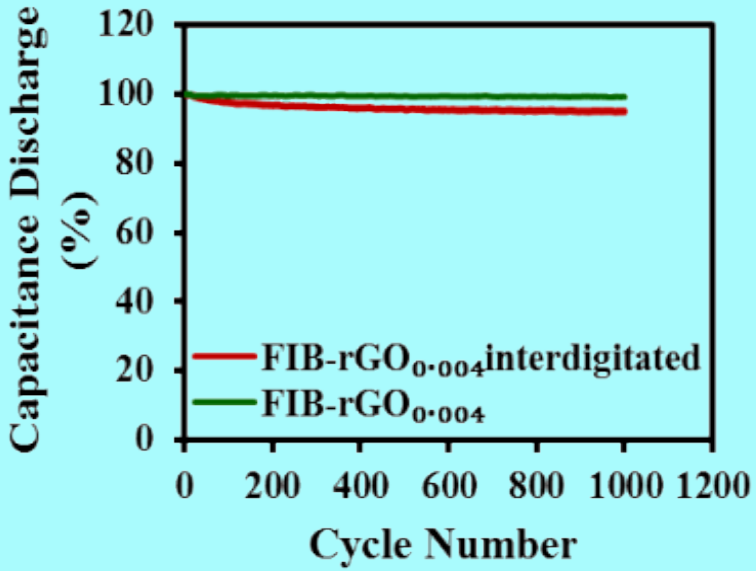


Banerjee *et al*, *Advanced Energy Materials*, 2015, 1500665

- At **small scan rates** (<10 mV), specific capacitance has **strong dependence** with scan rate
- At **large scan rates** (>10 mV), specific capacitance has **weak dependence** with scan rate

Influence of Miniaturization: GCPL



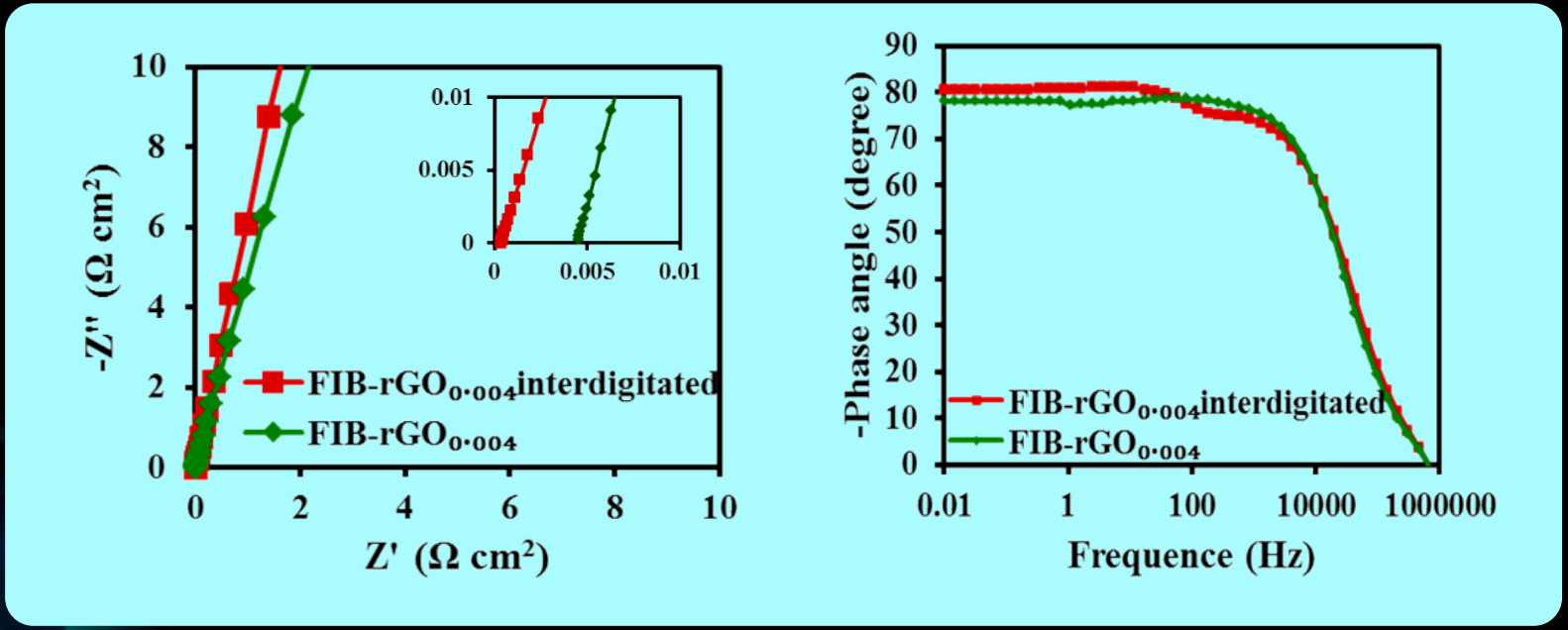


Banerjee *et al*, *Advanced Energy Materials*, 2015, 1500665

- Specific capacitance ➔ **104 mF/cm2**
- iR drop ➔ **0.02 V** for the interdigitated even at an ultrahigh current density of **45 mA/cm2**
- At least **95 %** specific capacitance retention capability after **1000 cycles**

Influence of Miniaturization: EIS

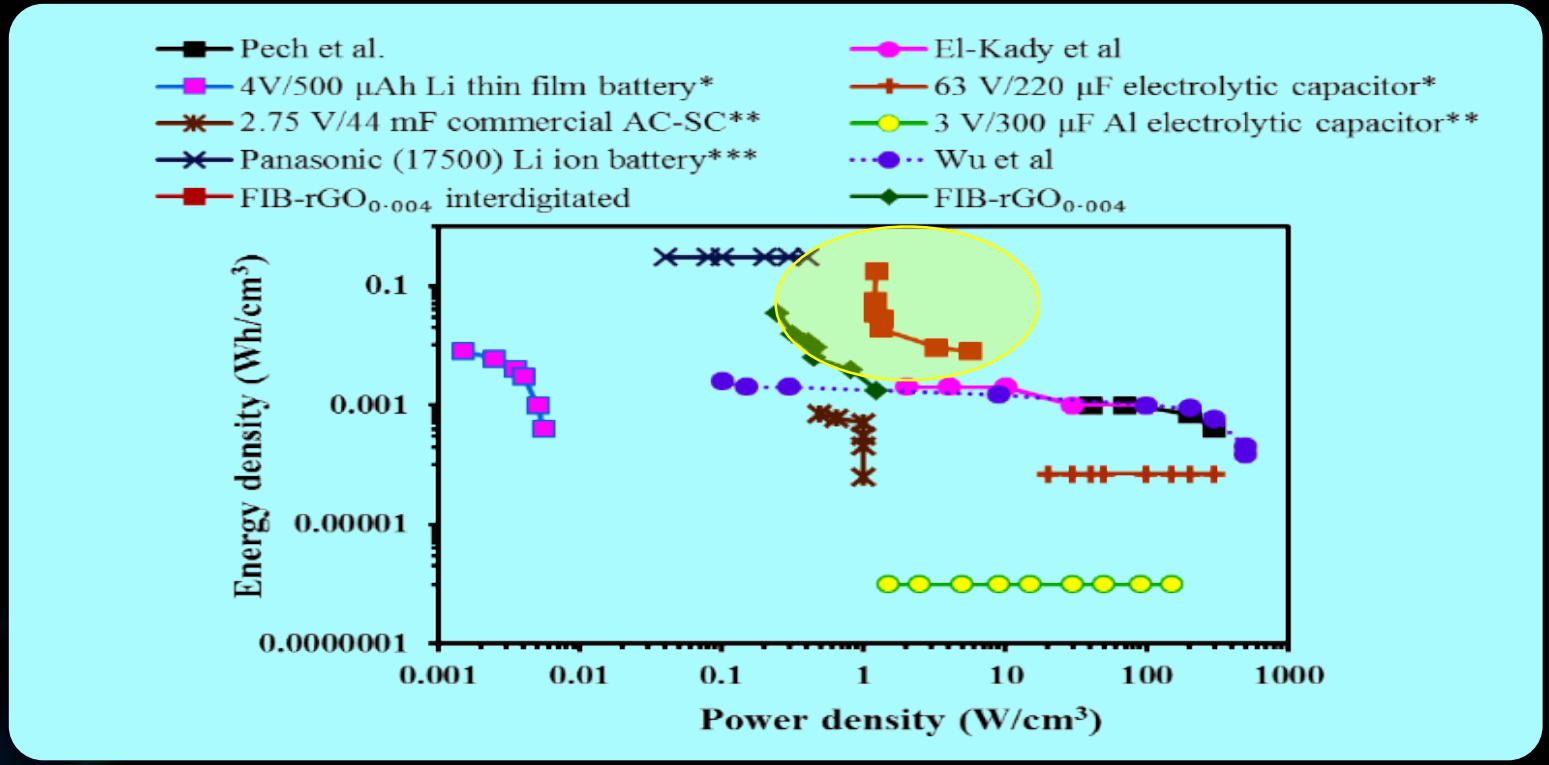
Ultra-low ESR, Ultra-fast response, and Large frequency range of operation



Banerjee *et al*, *Advanced Energy Materials*, 2015, 1500665

- Equivalent series resistance of the interdigitated electrode ➔ **0.35 mΩ cm2**
- Dominant capacitive behaviour at frequencies as high as **100 kHz**
- Response time of the interdigitated electrode ➔ **0.033 ms**

Ragone plot



Banerjee *et al*, *Advanced Energy Materials*, 2015, 1500665

Parameters	Ionic FiB rGO*	Laser reduced**
Response time (ms)	0.033	19
Energy Density (Wh/cm3)	0.173	0.002
Capacitance (mF/cm²)	102	2.314
Resistance (ESR, mΩ cm²)	0.35	3600

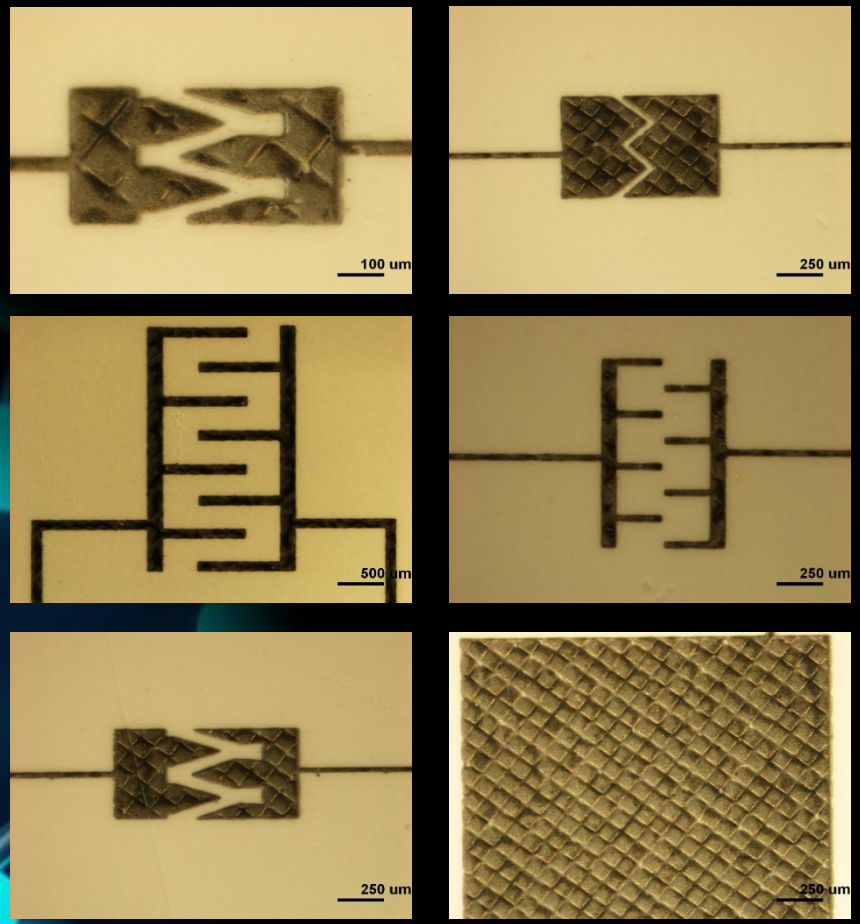
*Banerjee *et al*, *Advanced Energy Materials*, 2015, 1500665
**El Kady *et al.*, *Nature communications*, 2013, 4, 1475

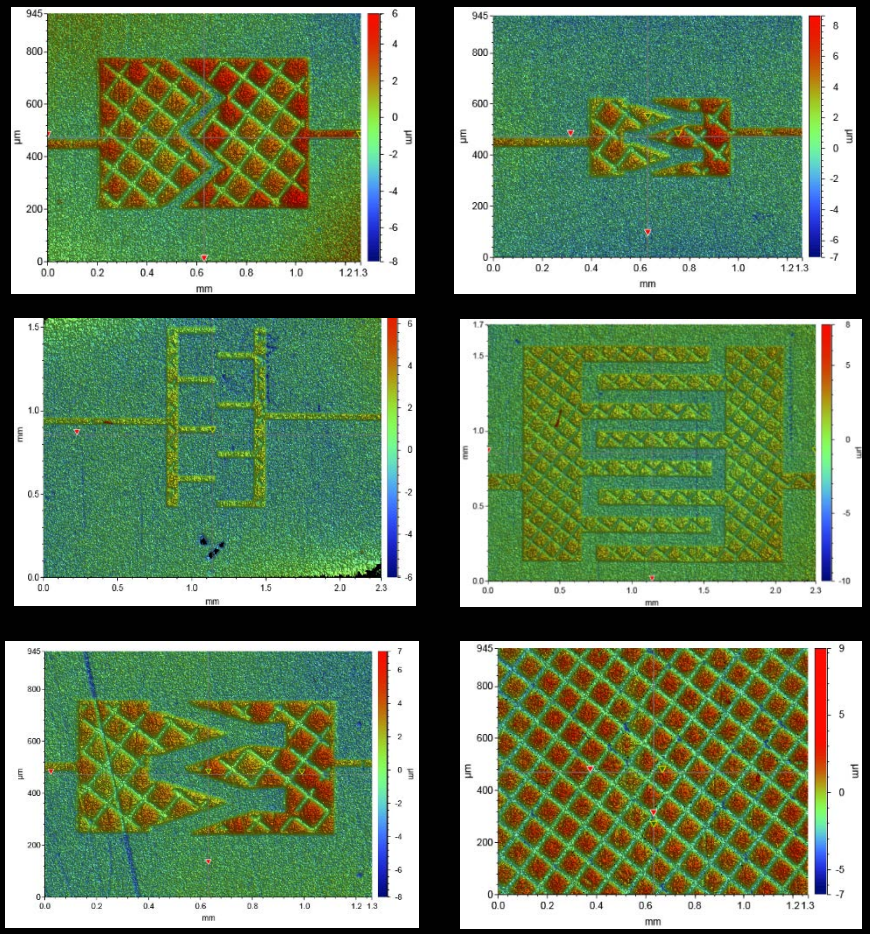
Manufacturing MICRENs with Printing

Our patent pending, rapid printing process for manufacturing MICRENS will contribute to scalability and cost advantages

Our Research

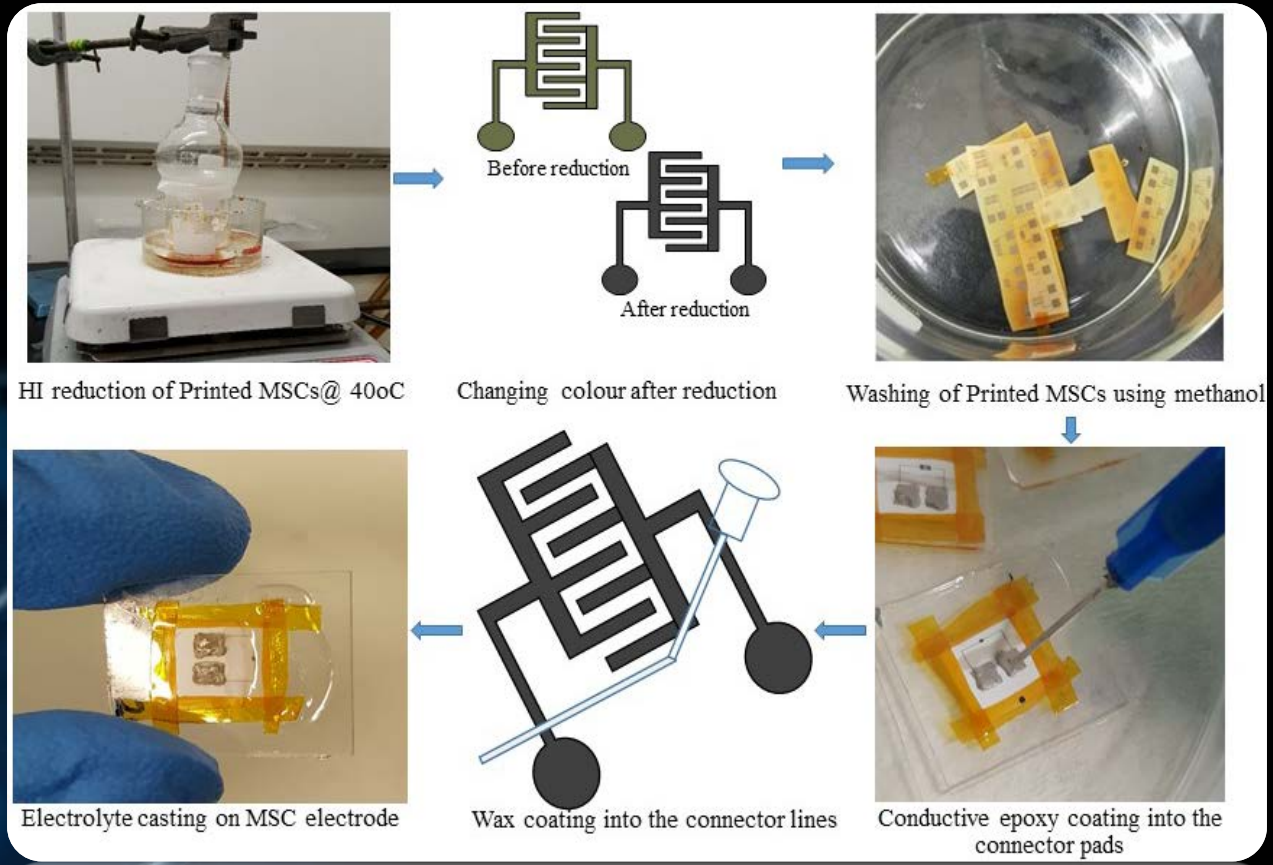
All-carbon electrode, inter-electrode distance < 50 µm, feature size 50-100 µm,



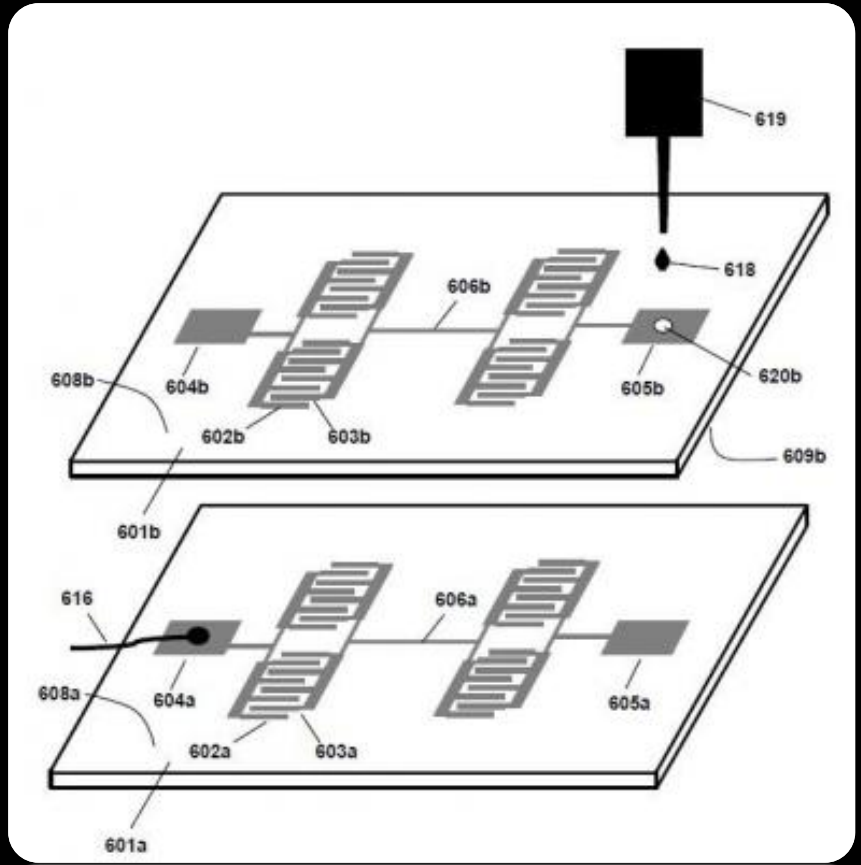


Printed Micrens using gravure printer

Fabrication steps of printed MSCs

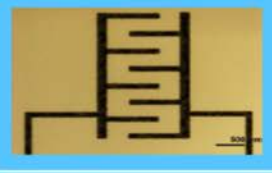
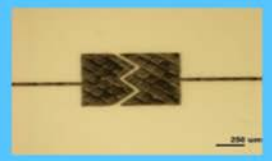


Stacking of printed MSCs

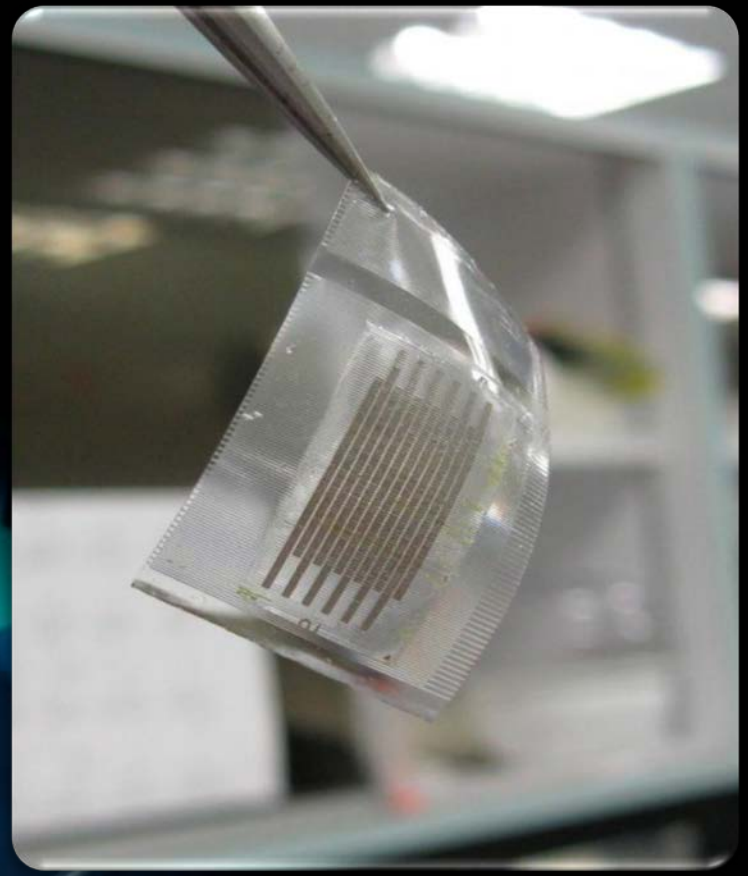


Research outcome

The outcomes from our research show that in printed MICRENns with ~ 30 µm interelectrode distance non-linear scaling of specific capacitance is observed.

Electrode structure	Applied Potential	Scan rate	Specific Capacitance (mF/cm2)	Energy Density (uWh/cm2)	Power Density (uW/cm2)
	0.5	10	1.089051	7.56285E-02	5.44
	0.5	20	0.939708	6.52575E-02	9.39
	0.5	50	0.621314	4.31468E-02	15.53
	1	10	4.55	1.26284	45.5
	1	20	2.98	8.2799E-01	59.6
	1	50	1.86	5.16694E-01	93
	1	100	1.25	3.46646E-01	125
	1	10	3.72	1.03316	37.2
	1	20	2.39	6.64355E-01	47.8
	1	50	1.33	3.69864E-01	66.6
	1	100	0.844	2.34334E-01	84.4
	1	10	28.2	2.75738	99.3
	1	20	17.7	1.73184	1.25
	1	50	10.3	1.00772	181
	1	100	6.74	6.59128E-01	237

Technical Challenges Remaining



Example of potential MICRENs form factor
Image Courtesy: Nanyang Technological University

- Finer and higher resolution printing (~20-30 micron features) for obtaining energy density enhancements by non-linear diffusion
- Irradiation based, chemical-free Graphene Oxide reduction technology
- Electrolyte printing technology for increasing the voltage window
- Overprinting of electrolyte on electrode (& vice versa) for decreasing dead-volume
- Tuning device property to target applications

The Target Performance

We have several generations of this technology planned and will explore potential commercial applications for each generation.

2018

- Interdigitated devices printed at feature size <100µm, thickness of device ~50nm
- Proof of concept for 3D stacked, printed devices and patent filing
- Begin exploring potential commercial applications

2019 1st Gen

- 3D stacked device with consistent defect free printing
- Better than existing supercapacitors 14 mF/cm3, 0.04 mWh/cm3, 1.5 mW/cm3
- High conductivity and reduced leakage current

2019 2nd Gen

- Commercial prototype comparable to activated carbon supercapacitor (2.75 V/44 mF), with energy ~0.6 mWh/cm^3 and power ~0.3 W/cm^3
- Potential commercial applications

2020 3rd Gen

- Printed supercapacitor electrodes with energy and power like a 4 V/500 µAh thin film Li-ion battery (2mWh/cm^3 and 0.3 W/cm^3)
- Safe, cheap materials – aqueous electrolyte etc

Timeframes may be varied depending on funding and market drivers.

Applications

- On-chip capacitors (µF-mF range) with variable voltage
- Implantable medical devices
- Wearables
- IoT devices
- Quantum capacitors

Collaboration Model

In our collaboration based model, we can work together with our partners in a number of ways

We need to properly understand requirements

For new applications we can customise the solution

Different applications will require innovative approaches to manufacturing

We can work together to leverage different funding sources for development work

Thank you

Simon Savage, Managing Director
simons@ionicindustries.com.au

Mainak Majumder, Lead Researcher
mainak.majumder@monash.edu