High energy density lithium-ion capacitors for pulsed load current applications

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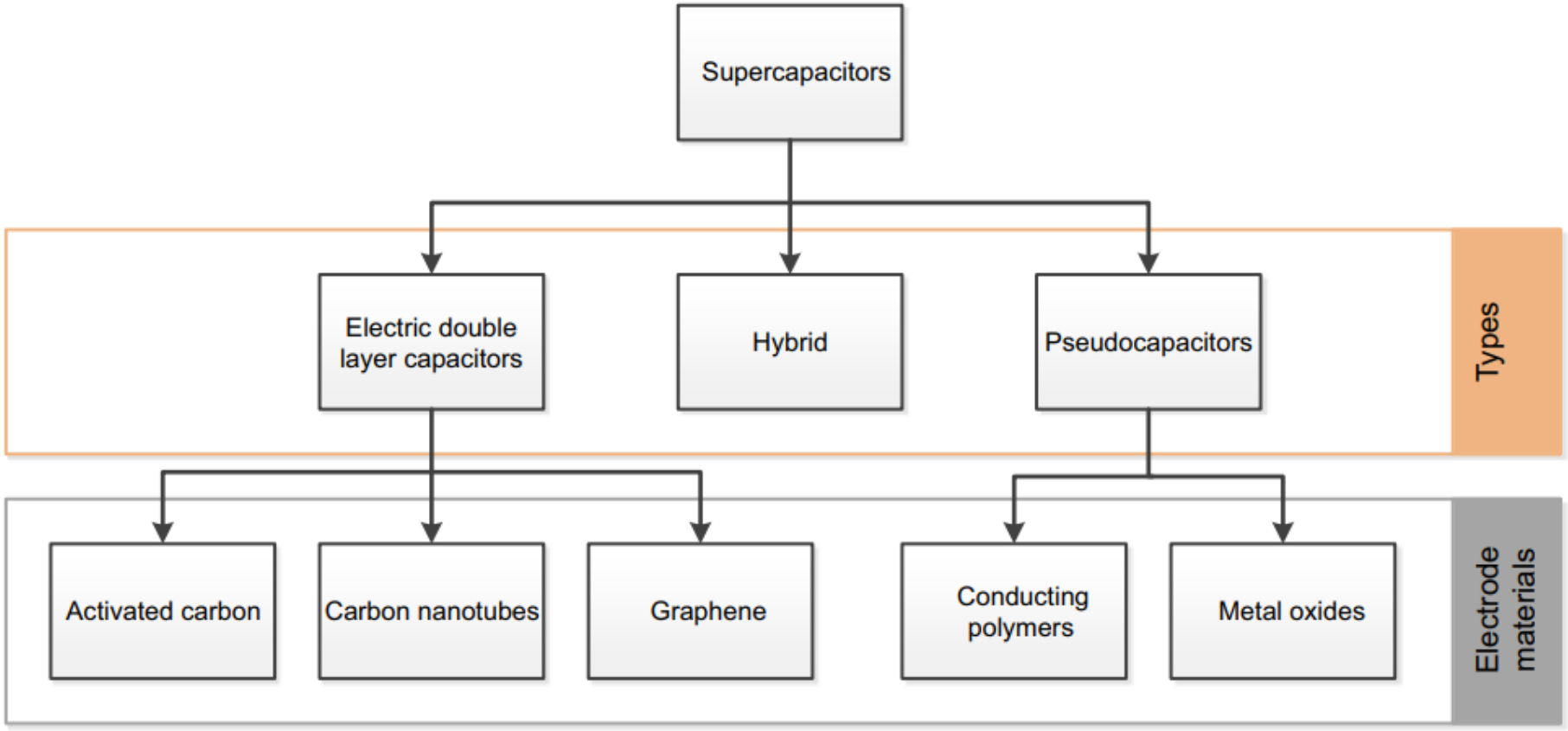
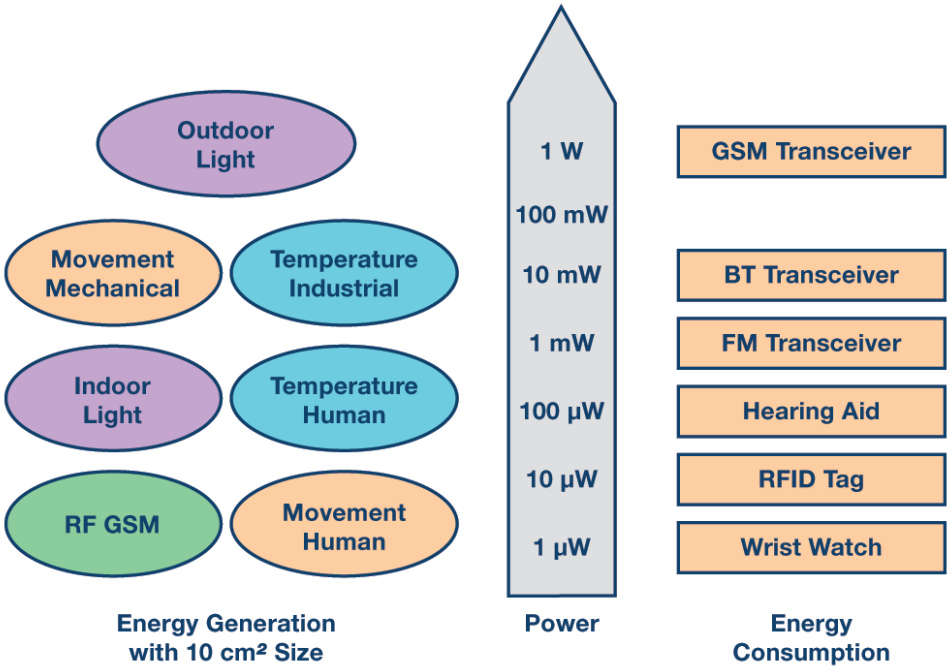


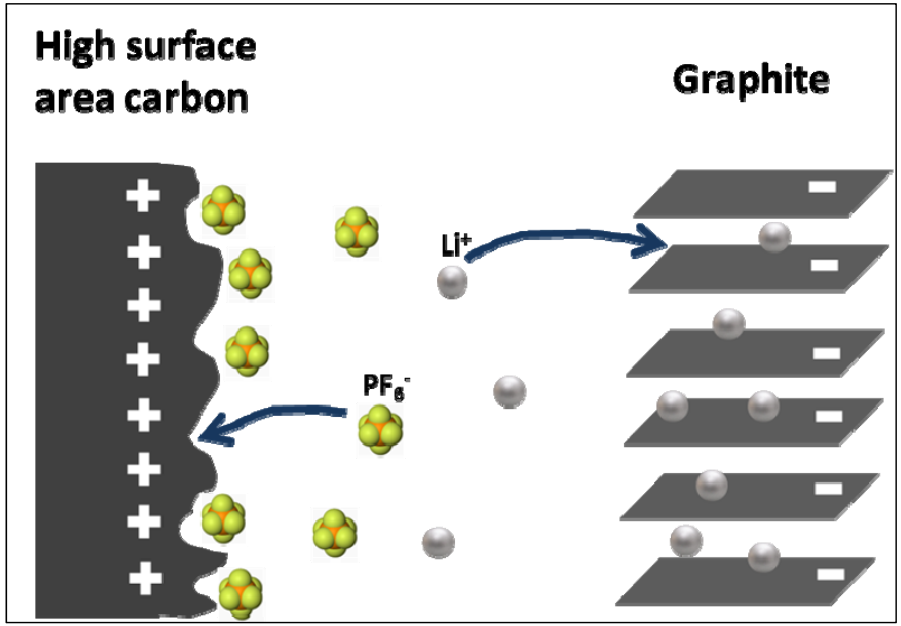
Renewable and Sustainable energy reviews, 58, 1189 -1206 (2016)

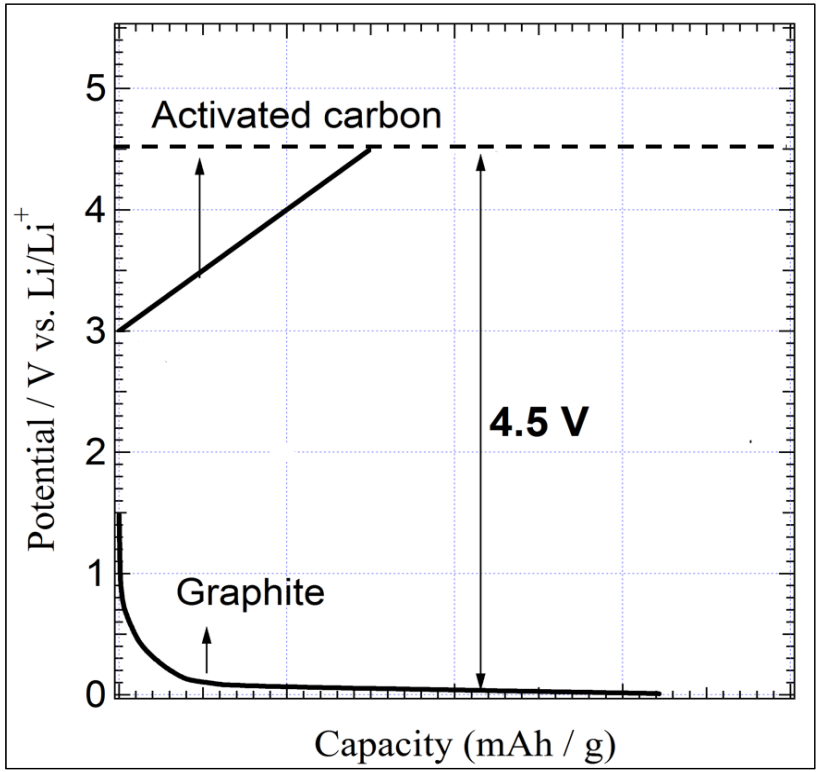
Desired capacitor characteristics for Energy harvesting and storage



- Low self discharge (minimize Electrode impurities)
- Low ESR (textural properties)
- Large capacitance (Pore size distribution)
- High voltage stability (Electrolyte decomposition)

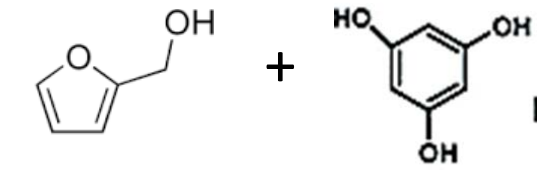
Lithium-ion capacitor technology





- Energy density limited by the specific capacitance of high surface area carbon cathode
- Power density limited by the C-rate performance of prelithiated graphite anode

Synthesis of bimodal porous carbon cathode

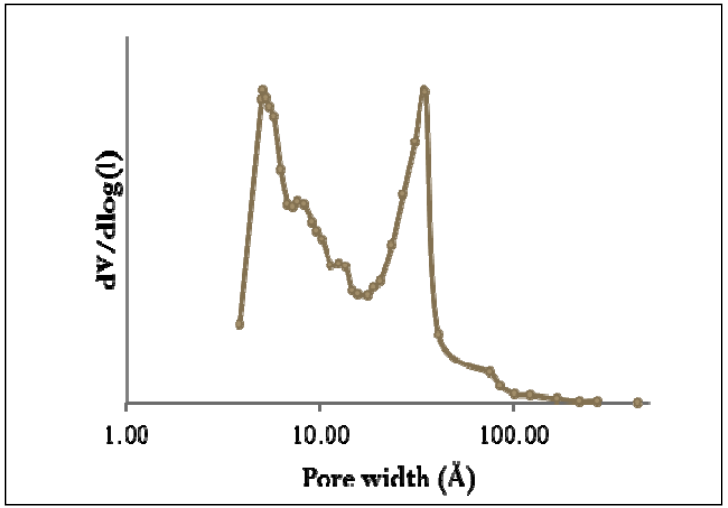


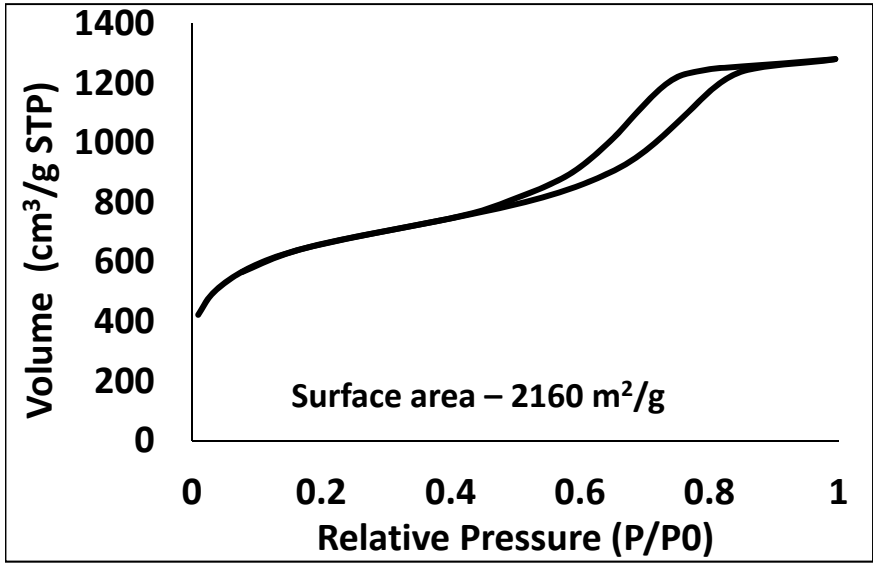
Furfuryl alcohol + Phloroglucinol + PEO-PPO-PEO

Simultaneous polymerization

Pyrolysis & activation

PFA_Ph

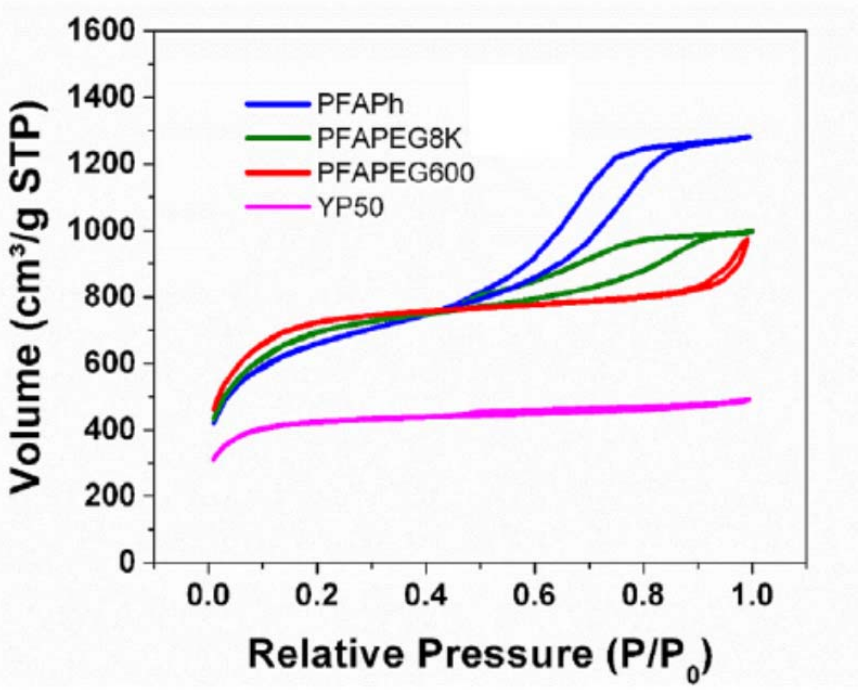


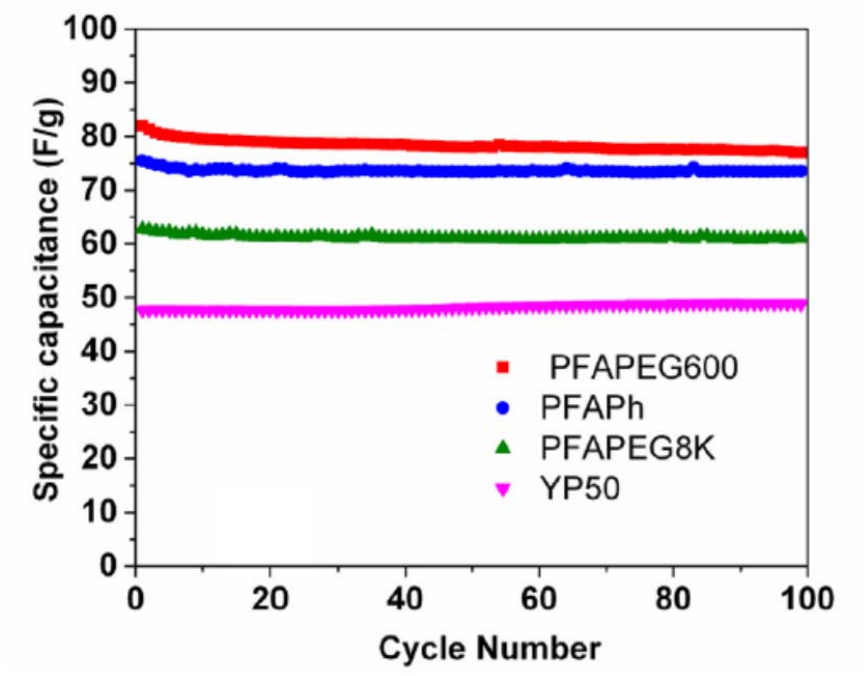


- High surface area carbons that have ultramicropores and mesoporosity in the range of 5 - 6 nm can be synthesized

Microporous and Mesoporous Materials, 196, 235 – 242 (2014)

Impact of pore size distribution on electrode capacitance

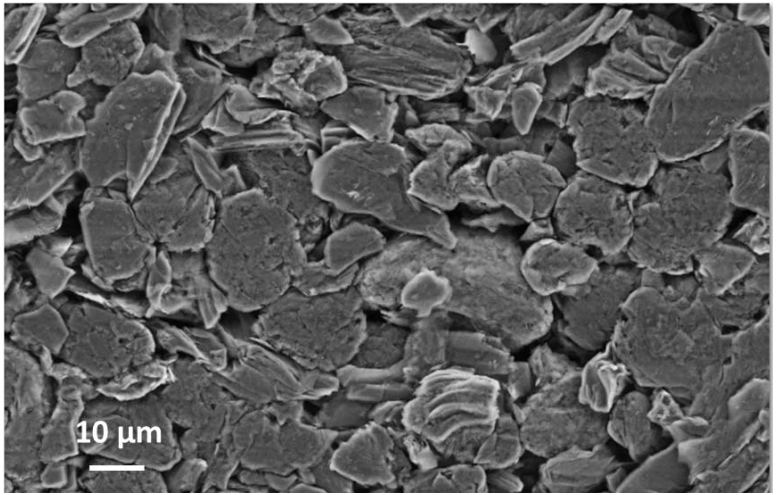




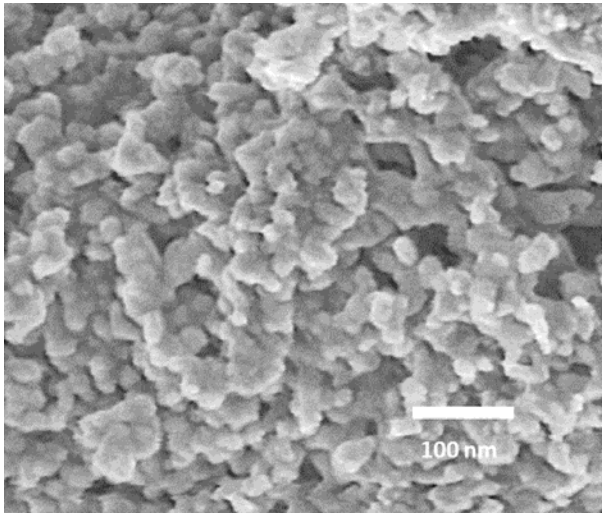
Bimodal porous carbon electrode has almost double the capacitance of the state-of-the-art commercial YP-50F carbon

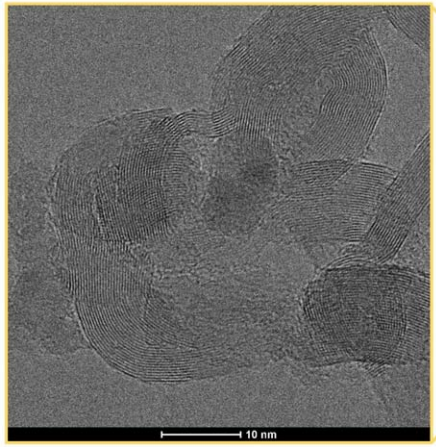
Improving rate capability of graphite

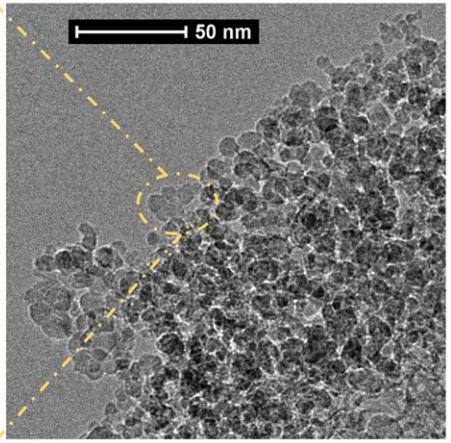
CMS graphite



Coalesced carbon onion

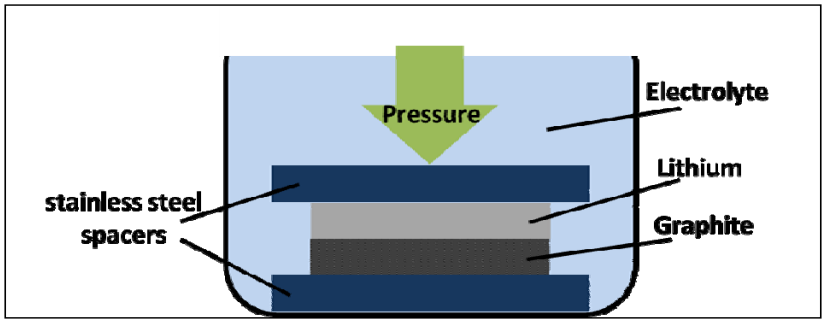




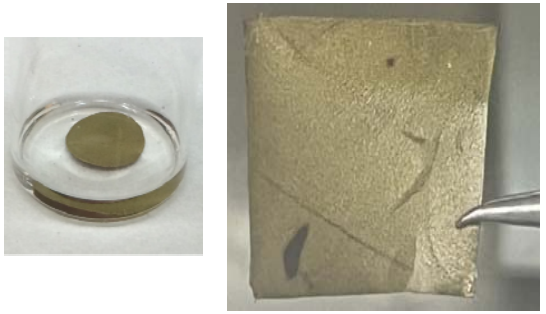


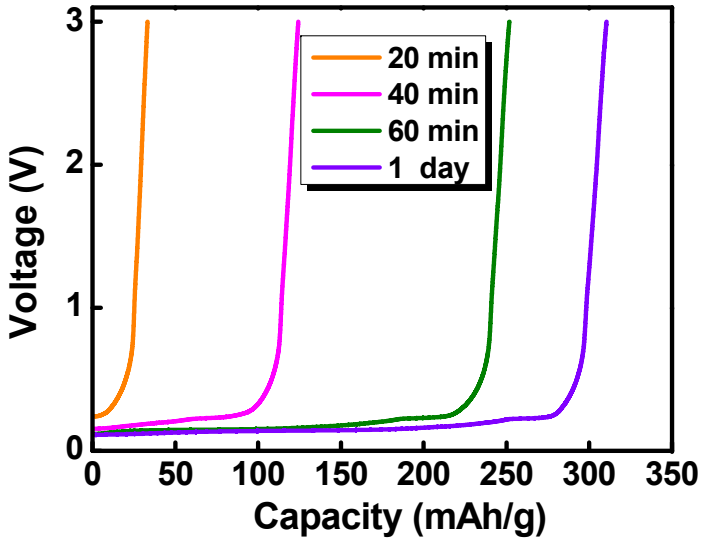
Carbon, 152, 89-97 (2019)

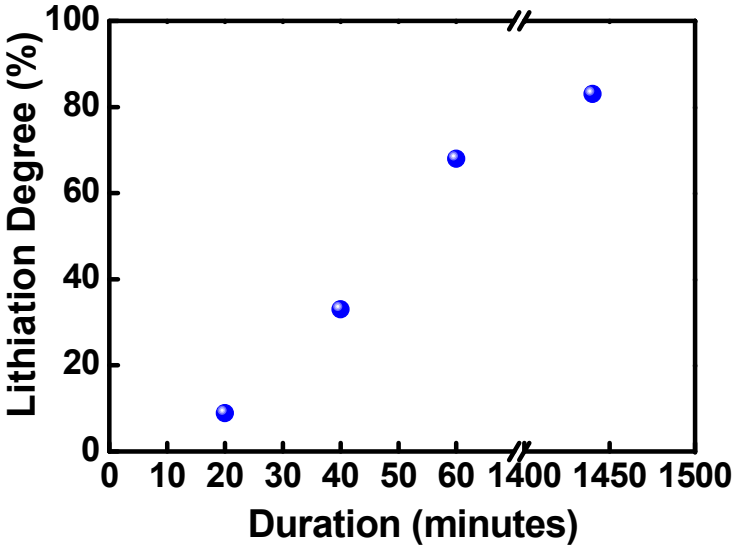
Prelithiation of graphite



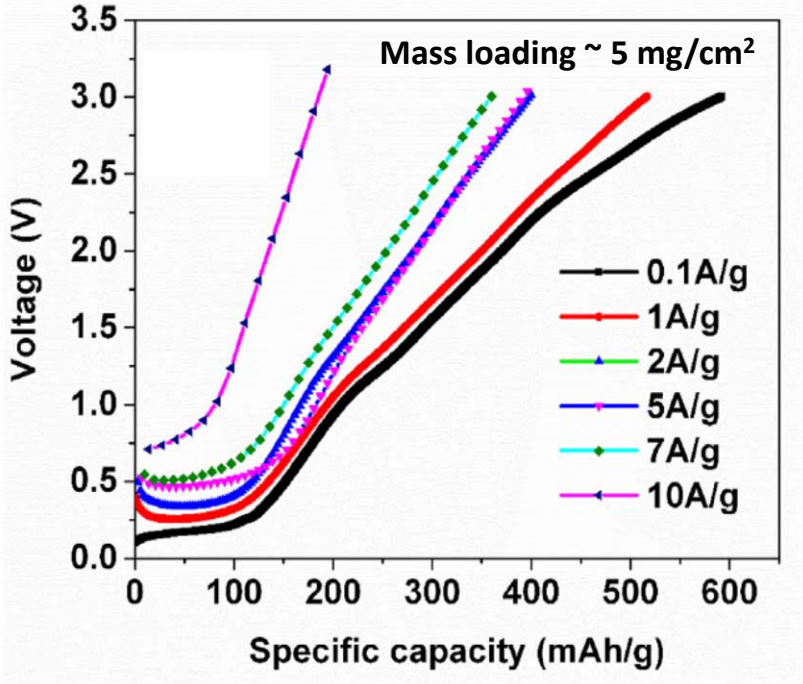
Lithiated graphite (golden yellow)

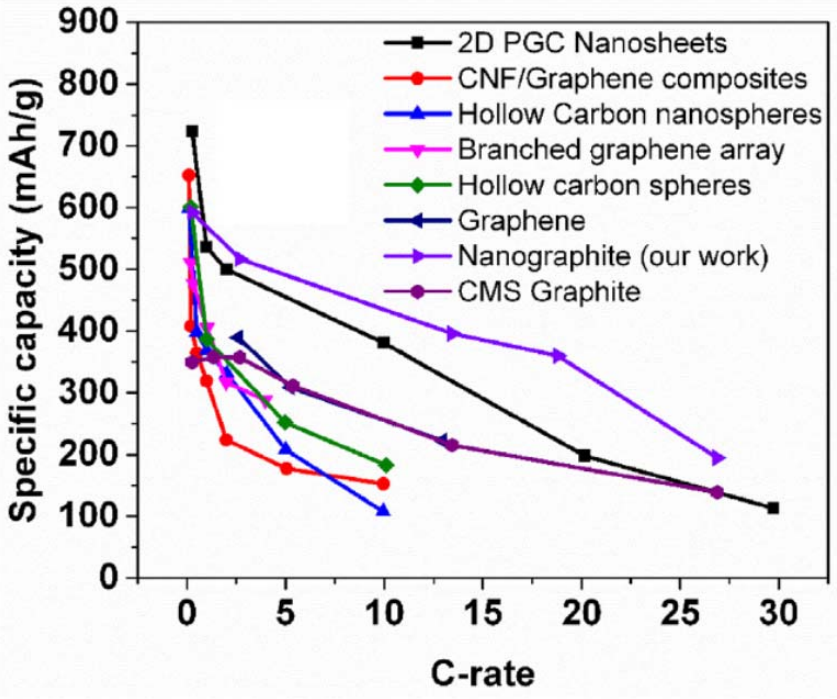






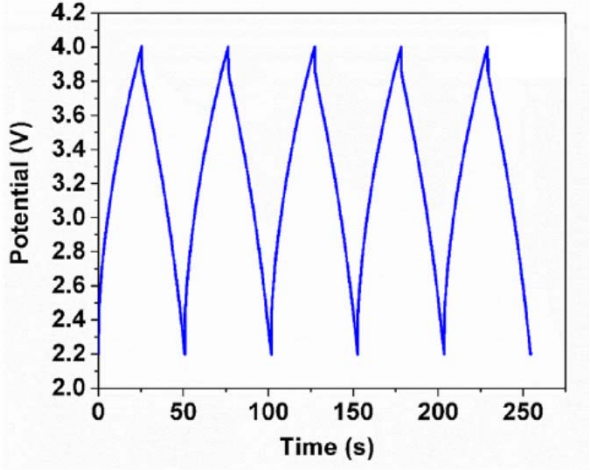
Half cell performance comparison of carbon onion-based anode against other high-rate anode materials

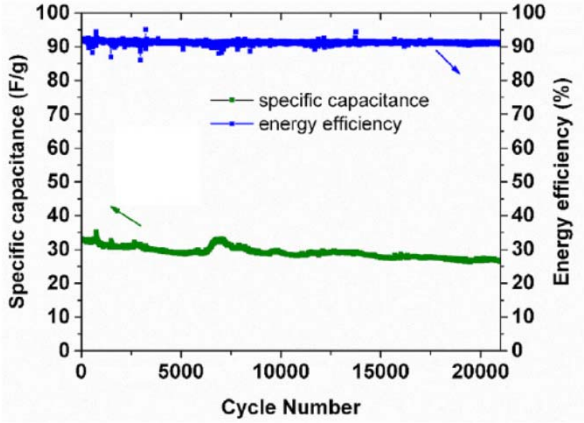


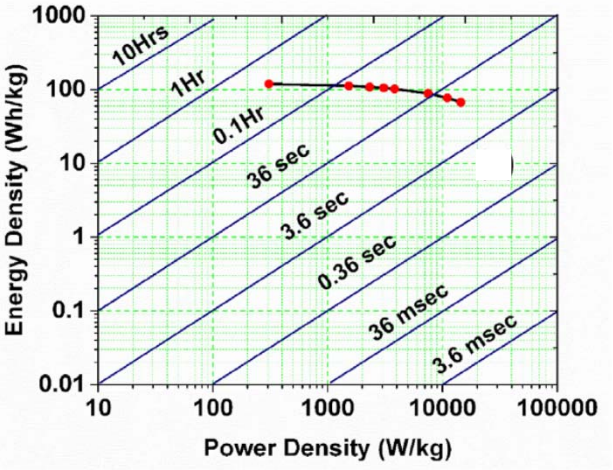


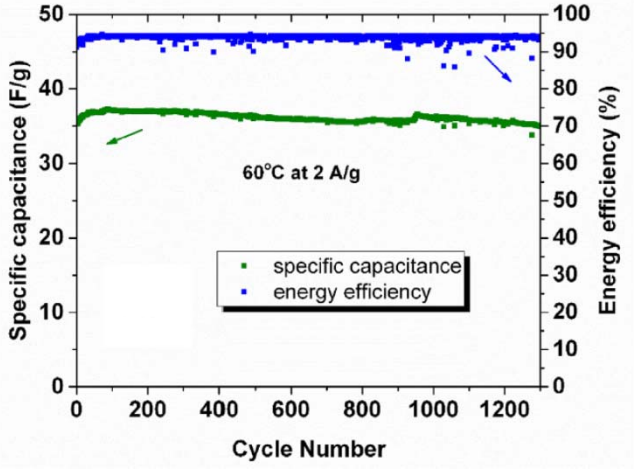
Coalesced carbon onion anodes have high-capacity retention (~400 mAh/g @ C-rate of 20C)

Performance of high-power lithium-ion capacitor





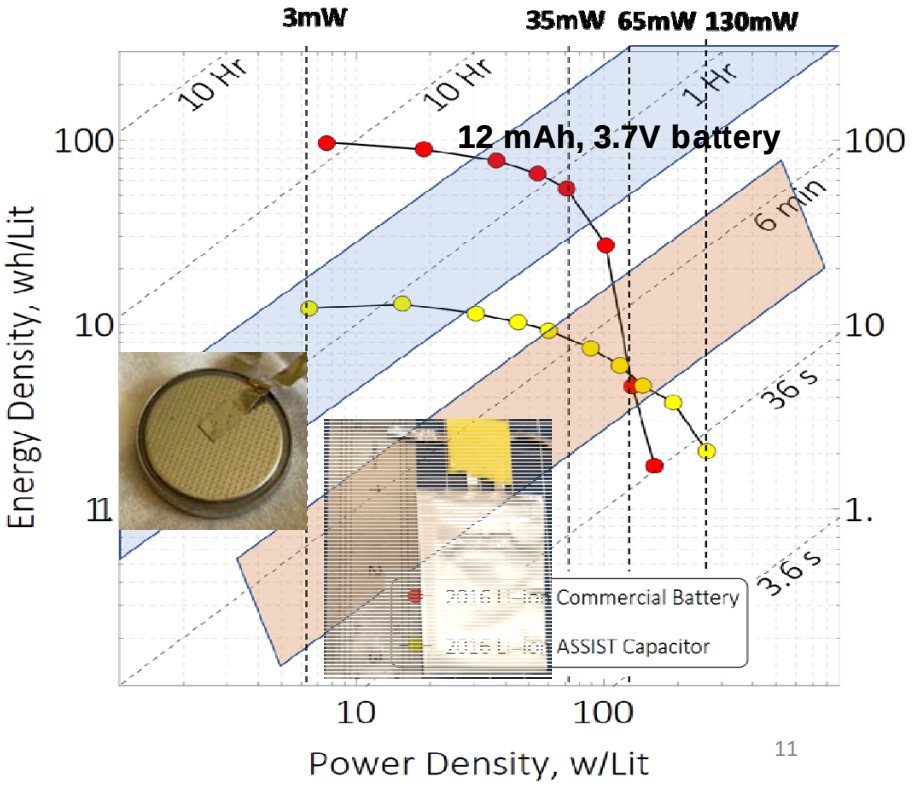




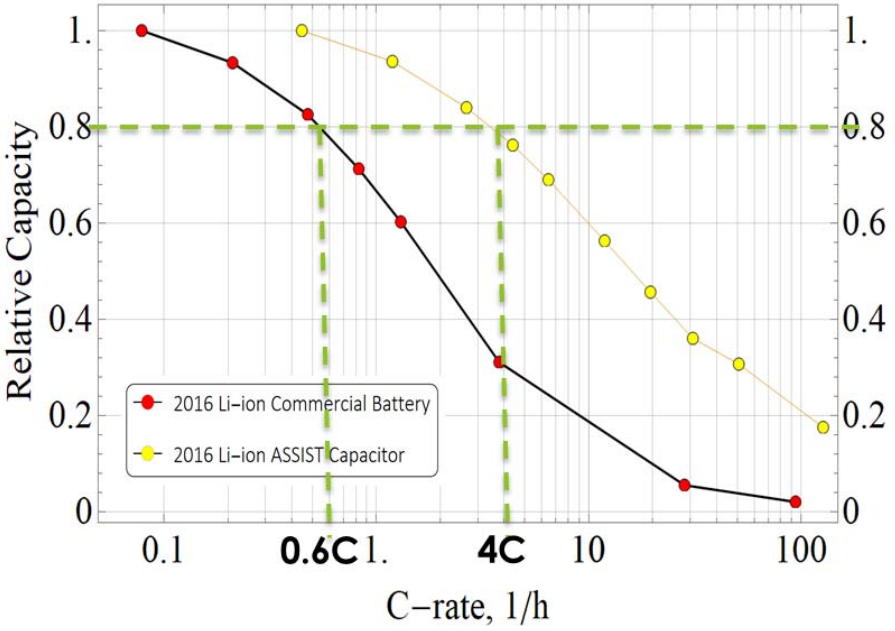
- Energy density of ~ 100 Wh/kg achieved at a power density of 10 KW/kg
- 80% capacitance retention over 21000 cycles
- Excellent thermal stability upto 60°C

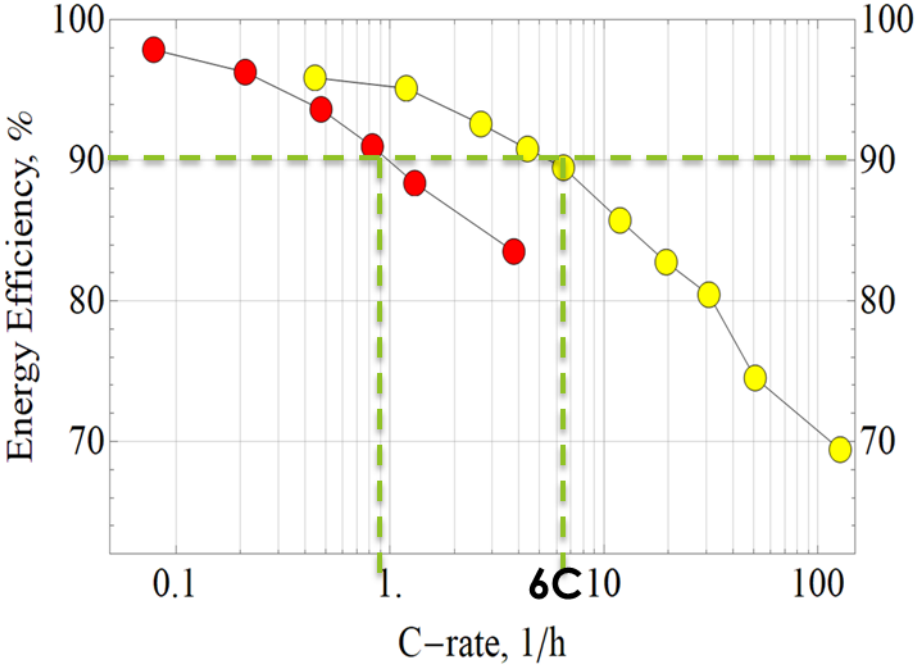
Performance of high energy density LIC2016 capacitor

Specifications	LIC2016
Cell Voltage	3.8V
Capacity	2.5 mAh (4.7F)
Nominal current	4C (10 mA)
Maximum current	50 mA for 36s
Operable Voltage range	2.2 – 3.8V
Leakage current	< 1 µA
Self discharge	10% over 2 months
Volumetric packaged energy density (Wh/l)	13 Wh/L



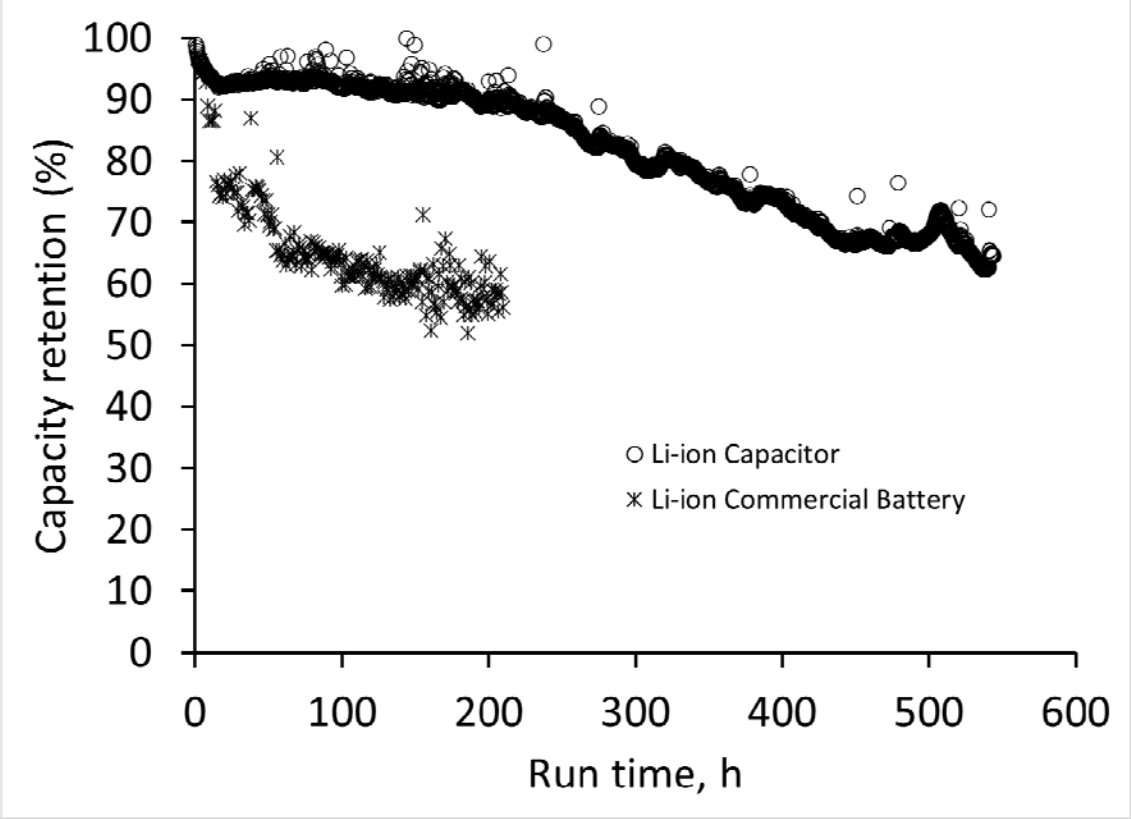
Performance comparison at different C-rates versus Li-ion rechargeable battery





- **LIC2016 delivers 80% of total capacity at 4C rate**
- **Energy efficiency as high as 90% achieved at 6C rate**

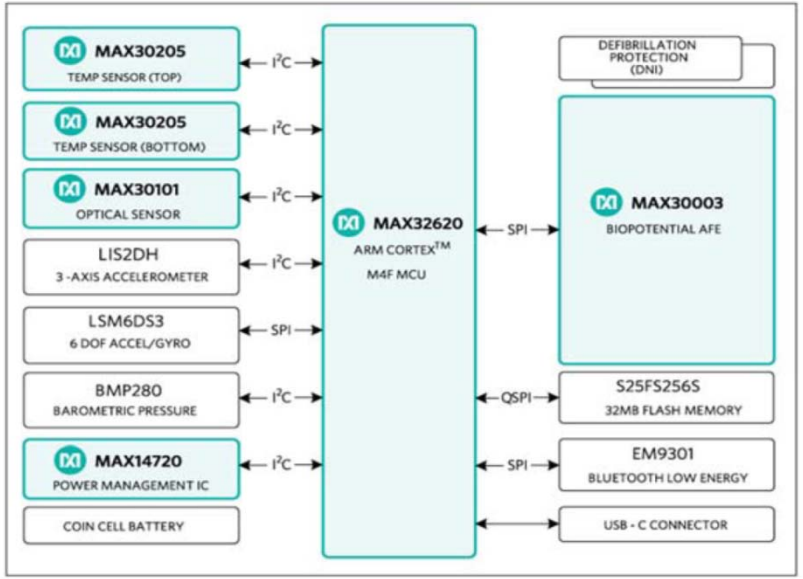
Comparison of cycle life performance versus battery



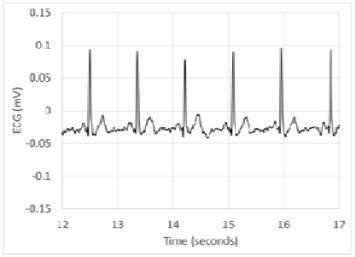
- Both capacitor and battery cycled at a constant current charge/discharge of 8 mA
- For similar capacity retention, Li-ion capacitor's cycle life is three times that of the battery

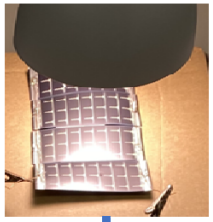
LIC2016 based demo

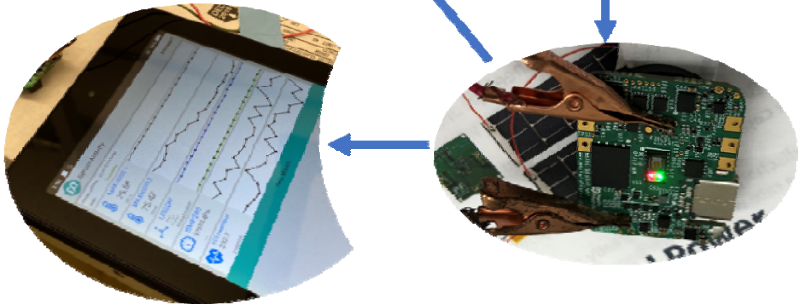
Maxim health sensor platform



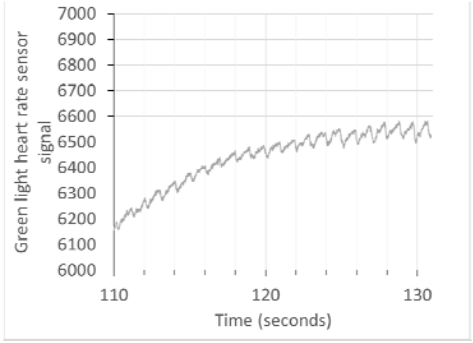
Replaced CR2032 battery with LIC2016 charged by flexible solar cell

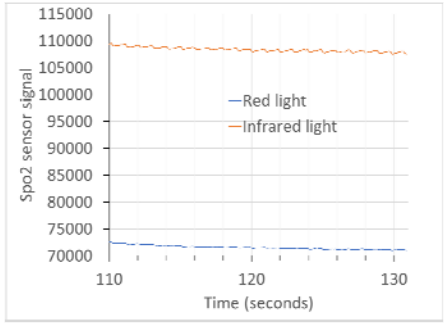




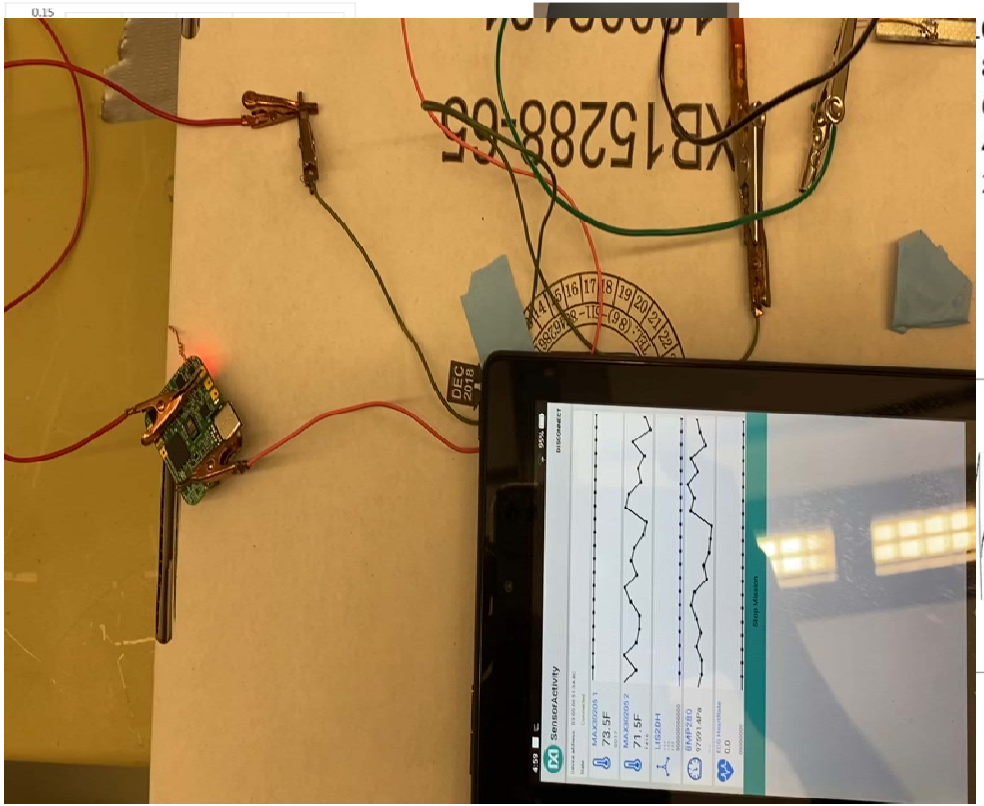


Pulse-ox and heart rate optical sensor

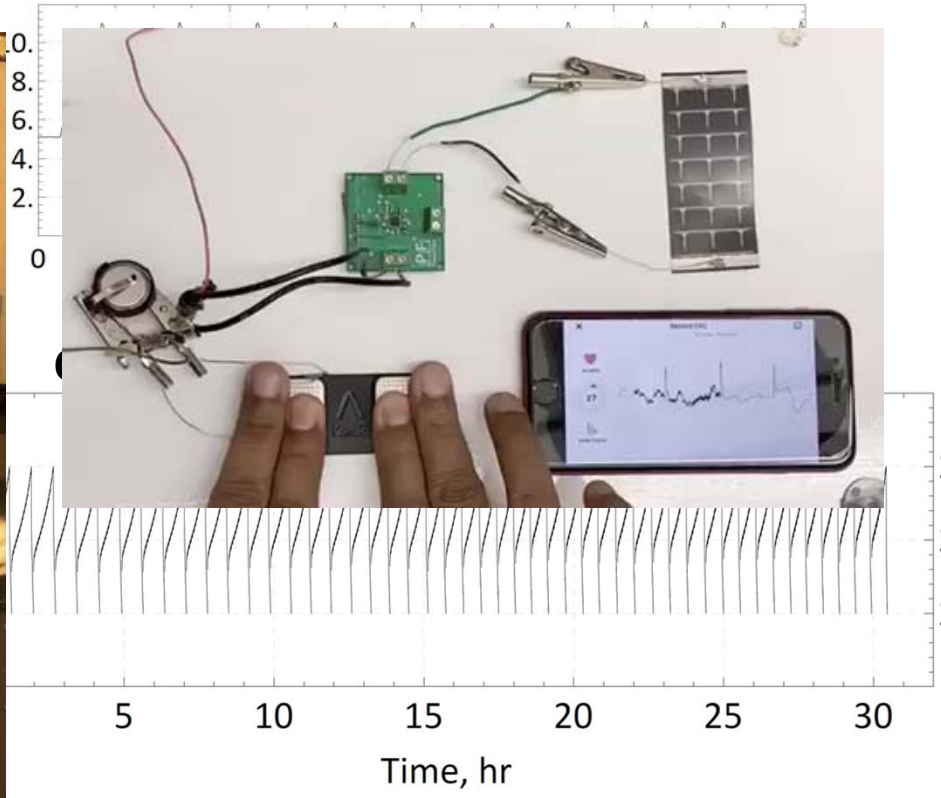




Demo based on capacitor powering wearable health sensor



Pulsed load current profile



Summary

- Li-ion capacitor fabricated using a high surface area carbon cathode with bimodal pore size distribution demonstrated higher specific capacitance
- Li-ion capacitor fabricated using a prelithiated coalesced carbon onion anode demonstrated excellent cyclability with 90% energy efficiency when charged and discharged at 2 A/g (discharge time ~ 27s)
- High energy density design allowed us to fabricate 13 Wh/L, 4.7F capacitor packaged in a 2016 coincell prototype
- The capacitor can be charged using solar cell to continuously run a health sensor platform
- The designed capacitor can offer significant advantages either as a standalone energy storage device or in conjunction with batteries for handling pulsed load current applications such as wearable technologies or IOT based systems

Acknowledgements

- NSF ASSIST Engineering Research Center
- Materials Characterization Laboratory at Penn State