Novel Carbon Materials for Advanced Energy Storage

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Overview

There is a heightened need for improved electrical energy storage systems for widespread energy-efficiency applications, including electrical grid storage, solar and wind energy, transportation, and industrial stop-go machinery. This effort is aimed at translating a discovery of nanoscale science – the tailored synthesis of mesoporous carbon materials through self-assembly – into a practical technology for producing improved electrode materials for electrical-double-layer capacitors, commonly known as super- or ultracapacitors.

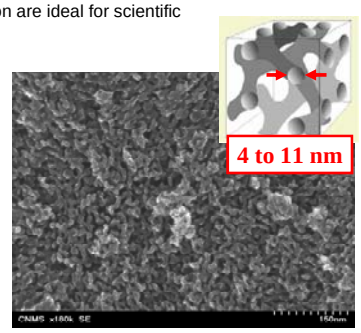
Experimental studies have demonstrated the capability to produce carbon materials with pore structures that provide high accessible surface area for ions of an electrolye. Testing indicates very good electrical storage performance, both in terms of high specific capacitance and frequency response (power). There is good potential for these materials to be produced at relatively low cost through scalable nanomanufacturing processes; thus, these materials show promise for continued development towards practical application.

Self assembly is path to tailored carbon structures

- Mesoporous carbon is synthesized by self-assembly of carbon precursors around soft templates
- Worm-hole structure provide highly accessible surfaces
- Uniform pores with a narrow size distribution are ideal for scientific investigation

Properties of ideal capacitor electrodes

- High surface area
- Tailored pore structure ⬅
- High pore volume
- Good electrical conductivity ⬅
- High purity ⬅
- Good corrosion resistance ⬅
- Relatively low cost
- Appropriate surface conditioning
- Optimum surface structure



Liang, C. D.; Dai, S., *J. Am. Chem. Soc.* 2006, *128*, 5316

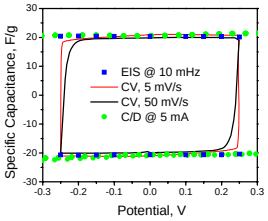
Dai, S.; Liang, C. US patent 2006 057051

Electrical testing indicates promising performance of self-assembled carbon

Capacitance of symmetric cell is evaluated with several measurements

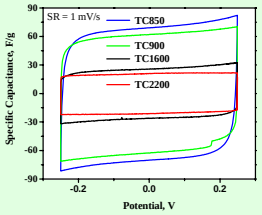
Details of measurements

- 1M H2SO4 electrolyte
- 2-electrode
- Cyclic voltammetry
  - Scan rate: 5 mV/s
  - 10th run
- Constant charge/discharge
  - Apply 5 mA
  - Terminal voltages
    - -0.5 & 0.5 V
- EIS
  - AC Voltage: 10 mV
  - DC bias: -0.25 to 0.25 V
  - Specific capacitance measured at 0.01 Hz



Specific capacitance and double-layer capacitance decrease with increasing graphitization temperatures

- Exceptional double-layer capacitance observed for an unannealed carbon.

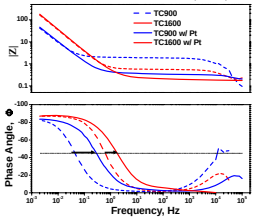


T_{gr} (°C)	BET (m^2/g)	C * (F/g)	C (μF/cm^2)
TC 850	407	68	16
900	354	62	18
1600	284	26	9
2200	269	21	8
CP 850	310	116	37
1200	285	32	11
1600	244	30	12
2200	220	19	9

* At 1 mV/s; TC=tape cast; CP=coated fiber paper

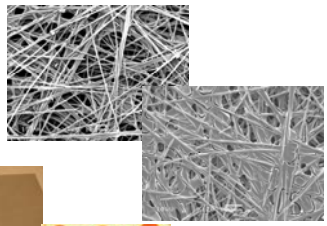
Fast response with high electronic conductivity and good contact with current collector

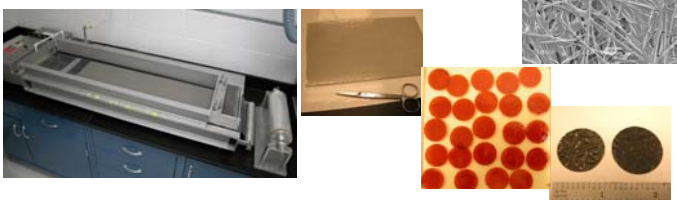
- 50nm sputter-deposited Pt on back side
- ESR @ 1kHz ≈ 0.7 Ω•cm2 with 25 μm separator and 1M H_2SO_4

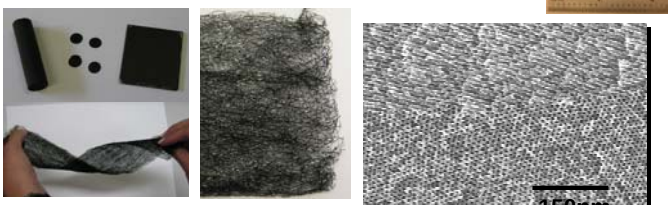


Mesoporous carbon can be prepared in several forms for electrodes with tailored properties

- Dip coat onto current collector
- Cast large block & pulverize
- Coat carbon fiber paper
- Tape cast free-standing films







Summary and outlook

- Copolymer surfactants prove an efficient template for synthetic mesoporous carbon.
- The pore size can be tailored at least 4 to 11 nm with a narrow size distribution.
- High specific capacitance is achieved for non-graphitized carbons, while high conductivity and rapid response are realized for carbons graphitized at high temperatures.
- These materials are expected to be ideal for investigation of electrolytes with large ions.
- Practical challenges for development and optimization of materials for ultracapacitors include:
  - Increasing pore volume for carbons with smaller pore dimension
  - maintaining (or restoring) high surface areas and specific capacitance when graphitized.

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