INTRODUCTION

Electric energy storage (EES) has emerged as an enabling technology for the widespread utilization of intermittent energy production from renewable energy sources. Electric double-layer capacitors (supercapacitors) have attracted particular attention because of their high power density and stable performance. A novel electrode material for supercapacitors is onion-like carbon (OLC). OLCs are spherical carbon nanoparticles consisting of graphitic onion shells with a diameter of 5-10 nm derived from nanodiamonds (ND) by thermal annealing. Compared to activated carbon (AC) with internal porosity, carbon onions present only external surface area, which enables superior rate handling and loading with redox-active materials like metal oxides without blocking pores.

CARBON ONION SYNTHESIS FROM NANODIAMONDS

Physical and chemical properties of ND-derived OLC can be tuned with annealing temperature, time, atmosphere, and the precursor ND.

- Surface area
  - During annealing the density decreases
  - Increase in particle volume
  - Increase in surface area
  - The increase is limited by redistributed carbon to larger graphitic structures due to carbon etching by desorbing surface functional groups

CARBON ONIONS FOR REDOX SYSTEMS

Material selection criteria
- The energy density of EDLC’s can be significantly increased by loading the carbon material with metal oxides, conducting polymers, or functional groups.
- By coating AC, the standard material in EDLC’s, with redox-active materials, pores are blocked and the composite suffers from the low conductivity of the AC.
- Carbon onions, in contrast, present only external surface area, which can be easily coated.

CARBON ONIONS FOR CAPACITATIVE ENERGY STORAGE

- Carbon ordering increases with annealing temperature
- Potential-dependent capacitance increases with carbon ordering
- Capacitance: 20–40 F/g (activated carbon ~ 120 F/g)
- Superior rate handling and high stability of high temperature carbon onions (high degree of carbon ordering and less surface functional groups)
- Annealing in argon enhances rate handling due to formation of few-layer graphene as conductive additive

Material/Inorganic Electrodes

- Carbon onion/manganese oxide hybrid electrodes
  - Carbon onions and activated carbon are hydrothermally coated with birnessite using KMnO₄
  - AC/birnessite presents high resistance and low capacitance due to pore blocking
  - OLC/birnessite shows enhanced capacitance with good rate handling behavior

Quinone-decorated carbon onion electrodes
- Synthesis of free-standing carbon onion/carbon fiber electrodes and functionalization with 9,10-phenanthrenequinones
- Capacitance increases with quinone-loading
- High capacitance of 280 F/g at 10 mV/s
- Excellent power handling (> 100 F/g at 2 V/s scan rate)