Growth of Carbon Nanotubes by Chemical Vapor Deposition for Supercapacitor Applications

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Introduction

Supercapacitors/Ultracapacitors:

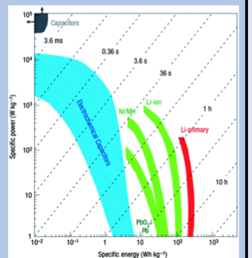
-Long life cycle

-Rapid charging

-Pulse power supply

-Higher energy

Storage[1] for capacitors



*Ragone Plot showing Energy Density vs Power Density for various energy storage systems

Uses and Applications:

-Hybrid and Electric cars

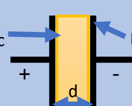
-Subzero energy storage

-Industrial energy management

-Could eventually replace batteries

Principle for Capacitance:

$$C = \frac{\varepsilon A}{d}$$



Simple Parallel plate capacitor Example

- d is separation between electrodes
- A is the surface area of the electrodes
- ε is the dielectric medium permittivity

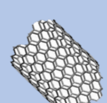
Carbon Nanotubes (CNT) Properties:

-Fast ion and electron transportation

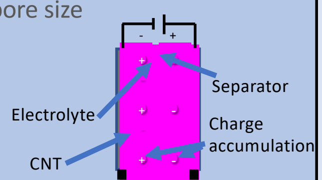
-High specific surface area (120-500 m^2g^{-1})

-Controllable pore size

-Stable design

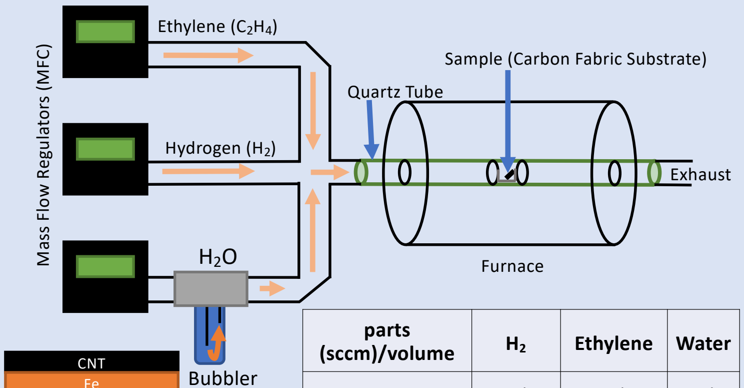


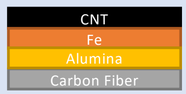
Structure of a CNT



Schematic of Supercapacitor

Chemical Vapor Deposition Set-up:



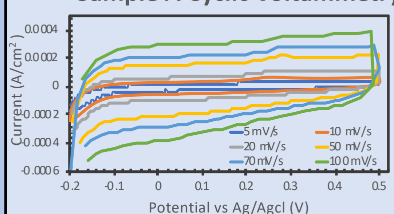


Electrode Structure

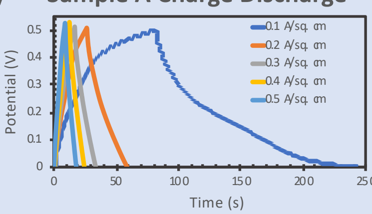
parts (sccm)/volume	H_2	Ethylene	Water
Sample A	10/1	20/2	50/5
Sample B	10/1	20/2	20/2

Results

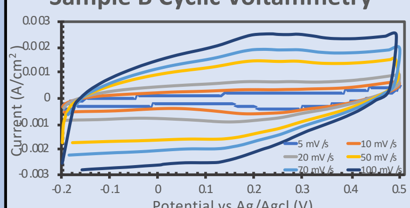
Sample A Cyclic Voltammetry



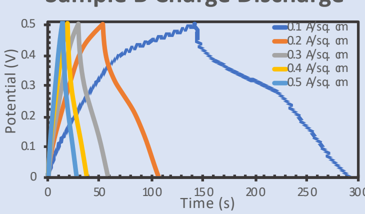
Sample A Charge Discharge



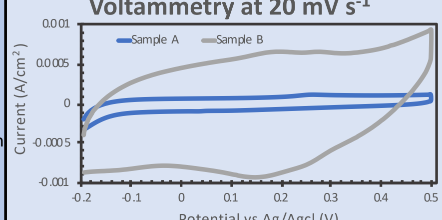
Sample B Cyclic Voltammetry



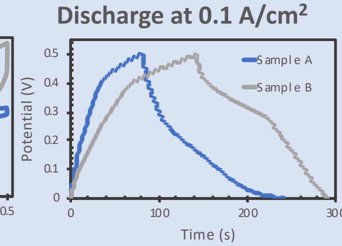
Sample B Charge Discharge



Comparison on Cyclic Voltammetry at 20 mV s^{-1}



Comparison on Charge-Discharge at 0.1 A/cm^2



Results Cont.

$$Specific\ Capacitance\ (F/g) = \frac{area\ under\ CV\ curve}{2 * mass * (Potential\ Window) * (Scan\ Rate)}$$

Specific Capacitance (F/g) at 5 mV/s	
Sample A	Sample B
9.33	24.41

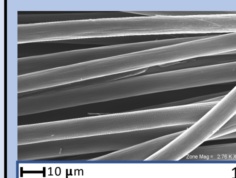
Reflections on data:

-Adjusting the H_2O to H_2 ratio optimized the reaction growth mechanism, thereby increasing the density of CNT growth

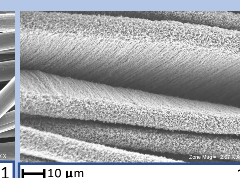
- This increase in density reflects in more surface area of the electrode material leading to more capacitance

- Reduced water vapor (weak oxidizer) during CNT deposition removes amorphous carbon on the catalyst thereby increasing the life time of catalyst particles[2]

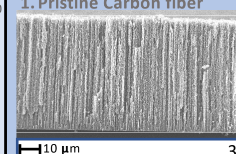
SEM Images:



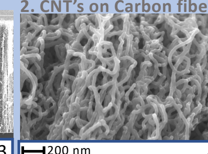
1. Pristine Carbon fiber



2. CNT's on Carbon fibers



3. Vertically aligned CNT's on Si wafer with total CNT thickness of 52 μm



4. Zoomed image showing CNT nanoforest of 50 μm CNT wall thickness

Conclusion

-The CVD process was optimized for the growth of CNT by adjusting the water to H_2 ratio.

-By reducing the water content, highly dense CNTs were produced leading to increase in specific capacitance from 9.33 F/g to 24.41 F/g

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SUMMER TRAINING EXPERIENCE IN ENGINEERING RESEARCH (STEER) BINGHAMTON UNIVERSITY

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NSF

[1]Zhoufei Yang, Jiarui Tian, Zefang Yin, Chaojie Cui, Weizhong Qian, Fei Wei, Carbon nanotube- and graphene-based nanomaterials and applications in high-voltage supercapacitor: A review, Carbon, Volume 141, 2019

[2]Kumar, Mukul & Ando, Yoshinori. (2010). Chemical Vapor Deposition of Carbon Nanotubes: A Review on Growth Mechanism and Mass Production. Journal of nanoscience and nanotechnology. 10. 3739-58. 10.1166/jnn.2010.2939.