Lightweight, wearable energy storage devices for Firefighters and First Responders

Paa Kwasi Adusei
Advisor: Vesselin Shanov
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Introduction

- Limitation to size, use and life span of technology is how it is powered.
- Energy storage Devices are created to solve this problem.
  - Devices that store energy that can be used when needed.
- Two main types
  - Batteries
  - Supercapacitors

- Energy storage devices based on fiber supercapacitors that can be integrated into firefighters and first responders clothing to power their equipment.

Carbon Based Capacitors

Commercial Supercapacitors have been fabricated from high-surface-area carbons.

- Advantages
  - High Surface Area (Specific Surface Area: 1000-2000m^2/g)
  - Low Cost
  - Commercial Availability
  - Well-established electrode production technologies

Theoretically for activated carbons with specific surface area of 1000m^2/g we expect capacitance of between 200-500F/g. In reality we end up with a few tens of F/g

- Disadvantage
  - Poor Electrolyte accessibility
    - Pores on the Surface Area are not accessible to ions of electrolyte.

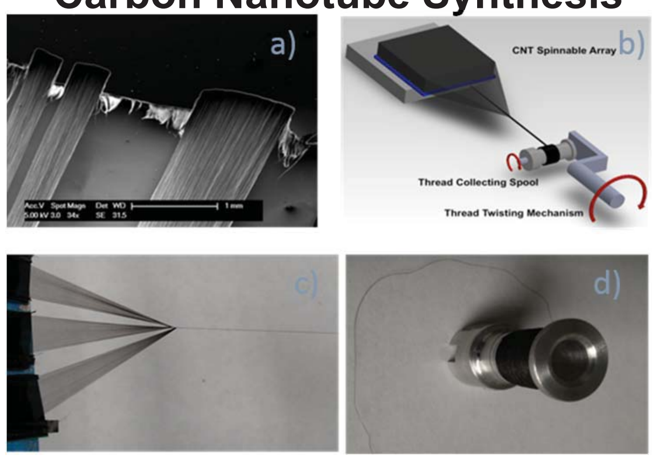
1)*Electrochemical Supercapacitors: Scientific Fundamentals and Technical Applications*, **1999**.
2)*Carbon Nanotub.*, Intechopen, **2010**, pp. 563–591.
3)*Carbon N. Y.* **2001**, *39*, 937.

Carbon Nanotube as Electrodes

- Can be assembled into sheets, papers and fibers
- It has high surface area 1315 m^2/g in Single wall Carbon Nanotube (less in multiwall carbon nanotubes)
- High Electrical Conductivity (5000 S/cm)
- High Charge Transport Capability
- High Mesoporosity (Pores between 2-50 nm in size)
- High Electrolyte Accessibility

3)*Carbon N. Y.* **2001**, *39*, 507.
4)*Phys. World* **1996**, *9*, 18.
5)*Science (80-.).* **2002**, *297*.

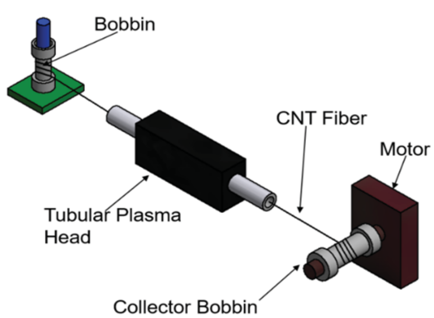
Carbon Nanotube Synthesis



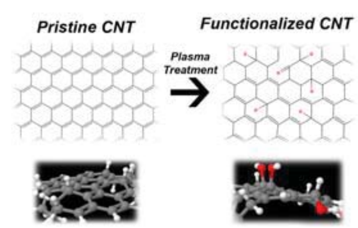
Spinning Process achieved by a home made set-up (pulling and twisting) to create fibers

Oxygen Plasma Functionalization of CNT Fibers

O_2 Plasma Functionalized CNT



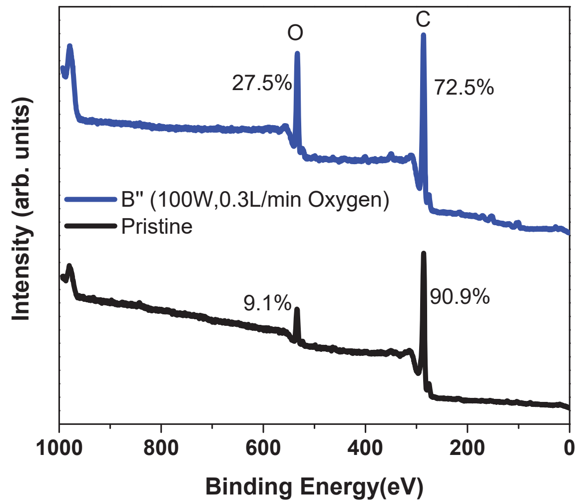
- Surfx Atomflo 400 system
- Two main speeds studied
  - 0.465 cm/s
  - 0.206 cm/s



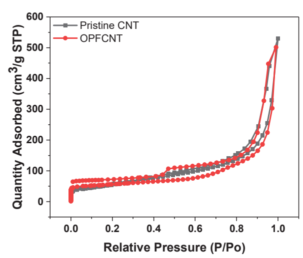
Samples	Power (W)	Oxygen (L/min)
A	60	0.1
B	100	0.3
C	140	0.55

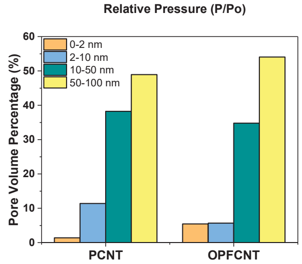
Study of Plasma Effects

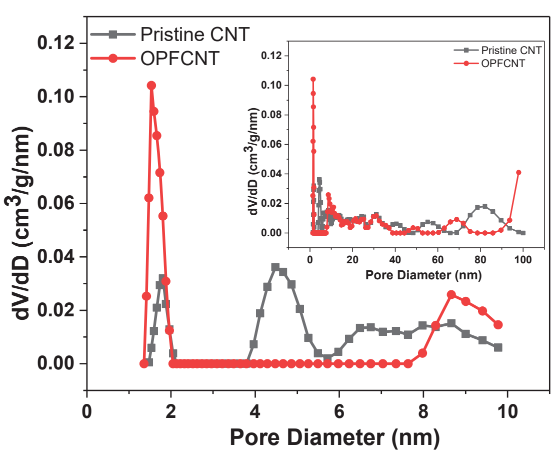
XPS



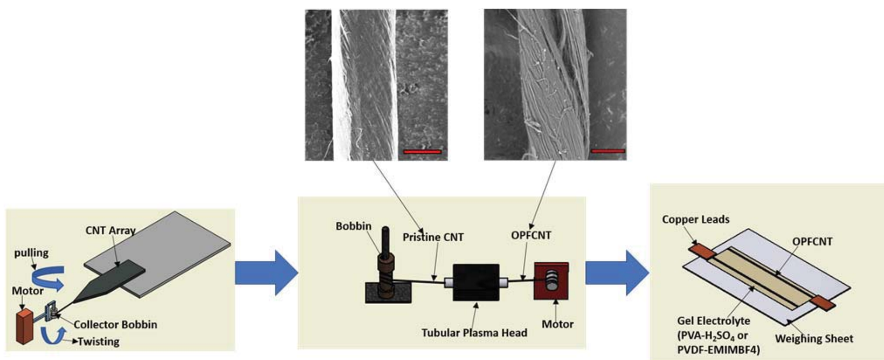
Study of Plasma Effects on Surface Area by BET





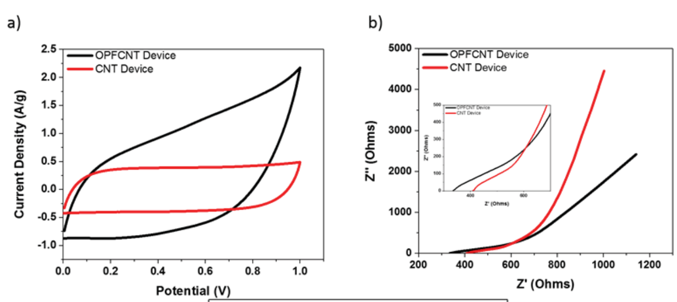


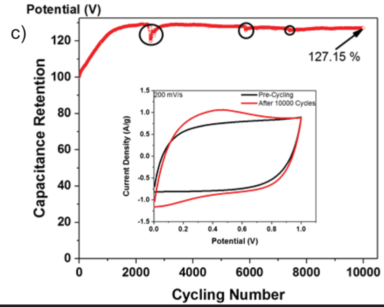
Electrode and Device Fabrication



SEM Images: 1000 Magnification Scale 25µm
PVA-H_2SO_4- 10 ml DI Water, 2 ml H_2SO_4, 1g PVA
PVDF-EMIMBF4- 4 ml Acetone, 0.5 g PVDF, 2g EMIMBF4

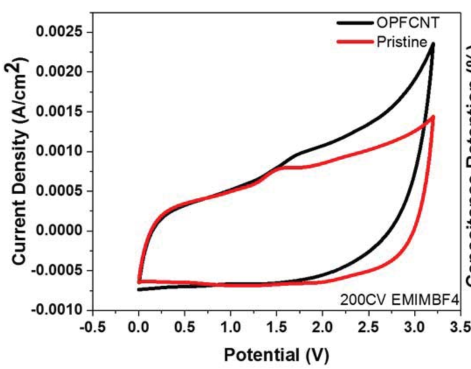
PVA-H_2SO_4 Device Data

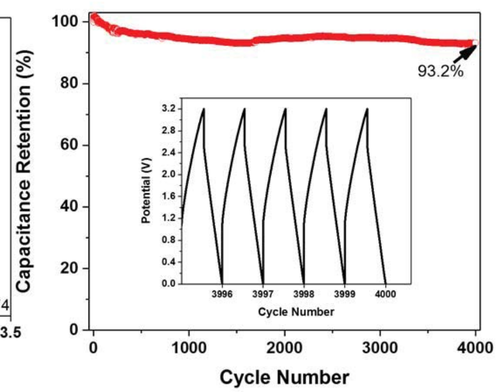




Cyclic Stability of OPFCNT H_2SO_4 Device

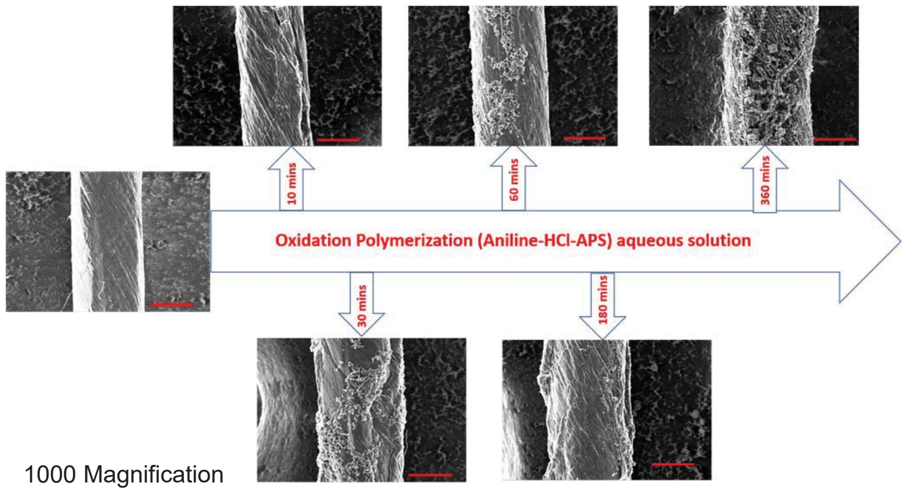
PVDF-EMIMBF4 Device Data





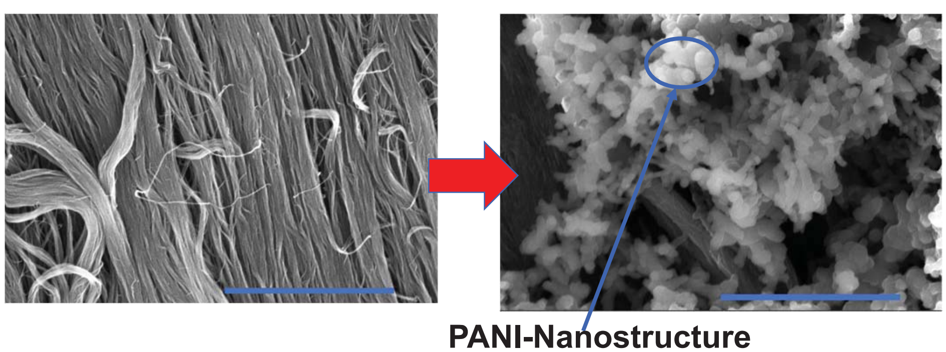
PANI-CNT Fiber Composites for Devices

SEM Images Route



1000 Magnification
Scale: 25μm

SEM (Pristine vs 1 hr Polymerization)



SEM Image of Pristine CNT fiber at 25000 magnification. Scale 2μm

SEM Image of 60-PANI-CNT fiber at 25000 magnification. Scale 2μm. PANI nanostructures observed on the surface

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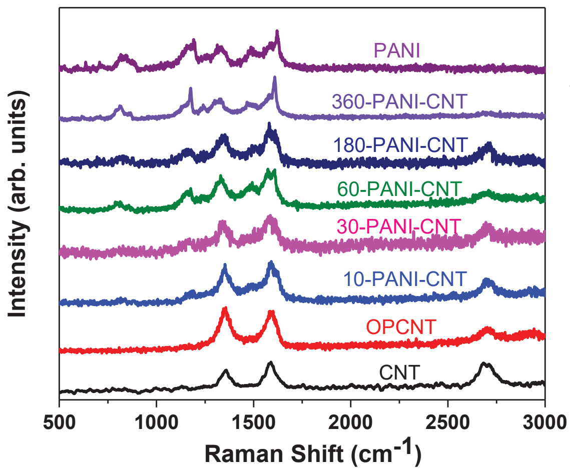
Raman Spectra



OPCNT-Oxygen Plasma Functionalized CNT

PANI-CNT composite fibers (10,30,60,180,360) – Number of minutes spent during Polymerization

Pristine CNT

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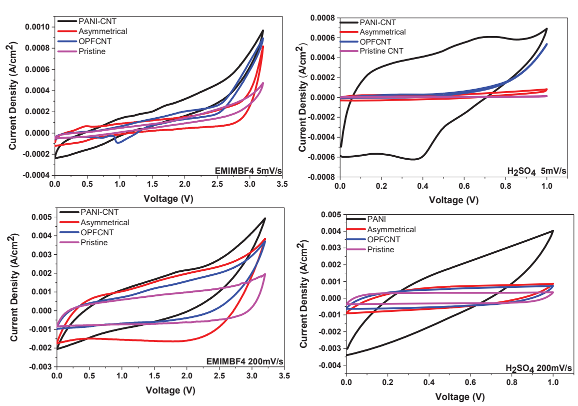
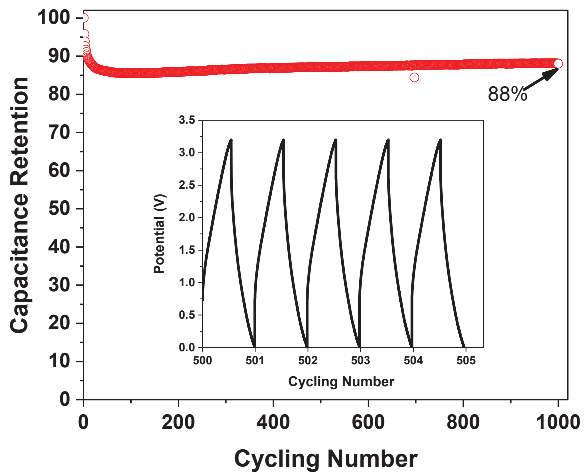
Cyclic Voltammetry- Devices



- **Devices have characteristic curves of Supercapacitors**
- **At low scan rates (5mV/s) redox reactions take place more so PANI-CNT devices have larger CV curves**

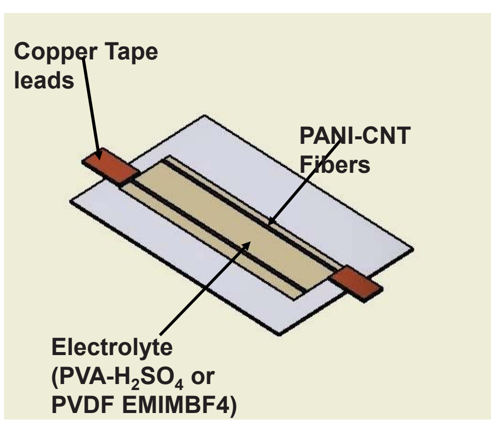
Cycling Test



Cyclic Stability for PANI-CNT EMIMBF4 device.

Inset: Galvanostatic charge/discharge curve after 500 cycles.

Device Schematic



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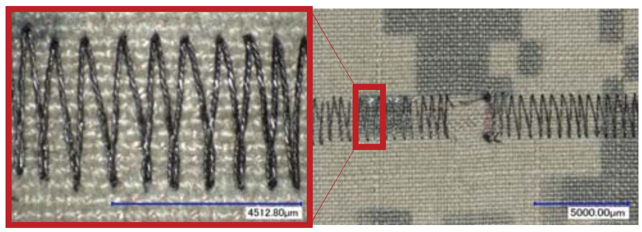
Stitching with CNT Yarn

- For Stitching, the new Brother LB6800PRW is being used

Brother LB6800PRW



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Stitched CNT Yarn at Work

Stitched CNT yarn used to light an LED

Optical Microscopy Image of CNT Yarn

Conclusions

- OPFCNT fibers give better capacitance and Energy Density values compared to pristine fibers
- The oxygen functional groups are shown to be on the surface of the fiber by XPS and relates to the increase in capacitance and energy density.
- Plasma functionalization of the fibers increases surface area of the fibers and alter the pore sizes which improves ion accessibility.
- The plasma functionalization process in this work can be applied to any fiber and is a continuous and controllable process.

Conclusions

- PANI-CNT composites were successfully synthesized by an oxidation polymerization technique
- The pseudocapacitive effect of the PANI was observed
- Devices created with EMIMBF4 had excellent retention and long-life stability.

Publications

- **Recently Accepted**
  - **Adusei, P.K.**, Hsieh, Y., Kanakaraj, S. N.,Fang, Y., Johnson, K., Alvarez, N.T., &Shanov, V. (2018). ***Fiber Supercapacitors based on Carbon Nanotube=PANI composite. InTech Book Chapter.***

- **Under review**
  - **Adusei, P.K.,** Hsieh, Y., Alvarez, N.T., Kanakaraj, S. N., Hsieh, Y., Gbordzoe, S., Fang, Y., Johnson, K.,., &Shanov, V. (2018). ***A Facile and Controlled Method of Oxygen Plasma Functionalizing Carbon Nanotube Fibers for supercapacitor Electrodes***
  - **Adusei, P.K.,** Gbordzoe, S., Kanakaraj, S. N., Hsieh, Y., Alvarez, N.T., McConnell, C.,Fang, Y., Johnson, K., &Shanov, V. (2018). ***Integration of Oxygen Plasma Functionalized Carbon Nanotube Fiber and Ionic Liquid for High-energy Fiber-supercapacitor***

- **Acknowledgment**

"This research study was (partially) supported by the National Institute for Occupational Safety and Health Pilot Research Project Training Program of the University of Cincinnati Education and Research Center Grant #T42/OH008432."

Thank you

University of Cincinnati
19th Annual
Pilot Research Project Symposium
October 11-12, 2018

Thursday, October 11, 2018

Presenter	Presentation Title
Alison Pecquet University of Cincinnati Environmental Health	"Immunotoxicity of PFCs (perfluoroalkyl compounds) Found in Fire-Fighting Foams" (Presentation PDF)
Cody Morris, PhD University of Alabama at Birmingham Kinesiology	"Comparing Health Status and Exposure Risk in Career Vs. Voluntary Firefighters" (Presentation PDF)
Claire Smith presenting on behalf of Haylee Min Bowling Green State University Industrial Organizational Psychology	"Negative Responses to Workplace Incivility in Home Care Workers" (Presentation PDF)
Jagjit Yadav, PhD University of Cincinnati Environmental Health	"Microbiome Changes as Markers of Exposure and Stress in Firefighters" (Presentation PDF)
Jennifer Perion University of Toledo Health Education	"Well-being of Youth Caregivers and its Effect on Pursuing a Career in Geriatrics" (Presentation PDF)
Weylin Gilbert presenting on behalf of Jooyeon Hwang, PhD Western Kentucky University	"Assessment of Diesel Particulates in Fire Departments using Different Exposure Metrics" (Presentation PDF)
Moderated by Gordon Gillespie, PhD, DNP, RN University of Cincinnati College of Nursing	"Poster Session I Q&A"

Friday, October 12, 2018

Presenter	Presentation Title
Jurate Virkutyte, PhD University of Cincinnati Environmental Health	"Establishment of an Aerosol Sampling Protocol using Passive Air Sampler (PAS) and Scanning Electron Microscopy (SEM)" (Presentation PDF)
Paa Kwasi Adusei University of Cincinnati Mechanical and Materials Engineering	"Lightweight, Wearable Energy Storage Devices for Firefighters and First Responders" (Presentation PDF)
Sathya Narayan Kanakaraj University of Cincinnati Mechanical and Materials Engineering	"Fabric Integrated Gas Sensors for First Responders and Miners" (Presentation PDF)

Vianessa Ng University of Cincinnati Mechanical and Materials Engineering	"Flame Resistant Nanofabric to Protect Firefighters Against Heat and Toxins" (Presentation PDF)
Moderated by Gordon Gillespie, PhD, DNP, RN University of Cincinnati College of Nursing	"Poster Session II Q&A"
Moderated by Gordon Gillespie, PhD, DNP, RN University of Cincinnati College of Nursing	"Panel Discussion of the Podium Presentation Topics"
Diana Schwerha, PhD Ohio University Industrial and Systems Engineering	"BEST Award Presentations and Closing Remarks"

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