Advanced Power Technology Development Activities for Small Satellite Applications

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Outline

I. Introduction
II. Small Spacecraft Technology Program Smallsat Technology Partnerships
    a) Demonstration of a Nano-Enabled Space Power System
    b) Development of a Lightweight CubeSat with Multifunctional Structural Battery Systems
    c) ALBus Small Sat power demonstrations at NASA
III. Conclusions
IV. Questions

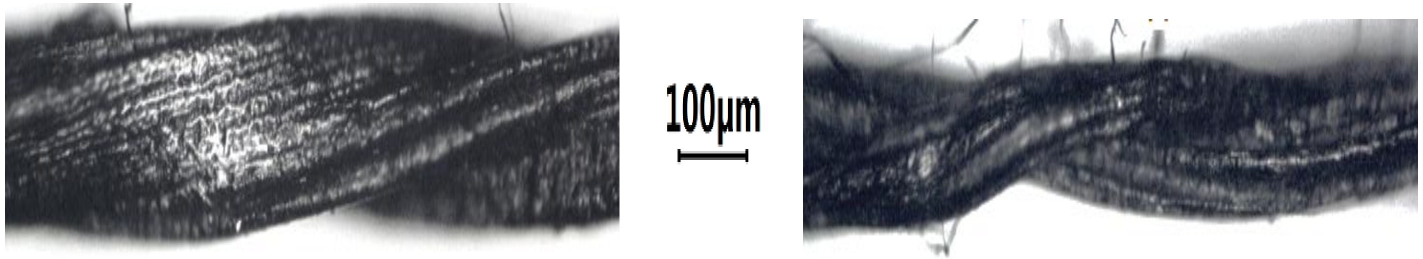
To Extend Mission Capability

- Challenges: Parasitic Mass, Power Efficiency Limitations
- Advanced power technology for space applications
  - Energy generation
  - Energy storage
  - Power management and distribution
  - Power systems architecture and analysis
- Advancements in such areas will impact the longevity and capabilities of these missions

Development of a Nano-Enabled Space Power System

- Nanomaterial-enhanced power system components to allow for reduced weight while maintaining or increasing capability.
  - Quantum dot / Quantum well solar cells
  - CNT enhanced lithium-ion batteries
  - Carbon nanotube (CNT) wire harness
  - CNT thermoelectric energy harvesting
- Nanomaterials
  - ✓ Significant weight saving
  - ✓ Minimal change in cost
  - ✓ Increase in available space

Optical Microscopy of Twisted and Braided metal-free CNT Harness, exceeding 1x10^{6} S/m in electrical conductivity

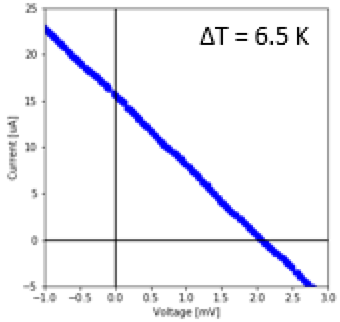


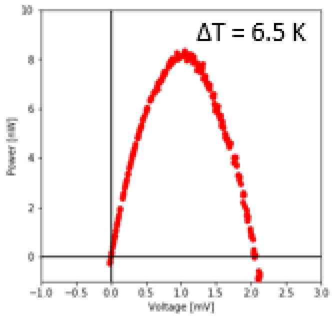
3 Ply Laid | 3 Ply Braid

Evolutionary advancements **in each technology when combined can translate into *revolutionary changes* at the system level to provide higher conversion efficiency and energy density to extend mission capability.**

Progress to Date

Demonstrated thermoelectric power generation from SWCNT TE device, producing over 8 nW from 3 paired couples against a temperature gradient of 6.5 K





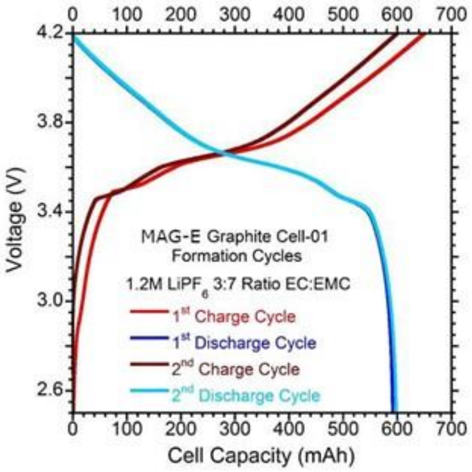
Heat Management & Energy Harvesting

QD/QW Cells

Increased radiation tolerance extending lifetime. Spectrally tuning the middle (GaAs) cell bandgap leading to higher current densities. Highest QD V_{OC} to date. replacement PV cells to be integrated with Clyde Space boards

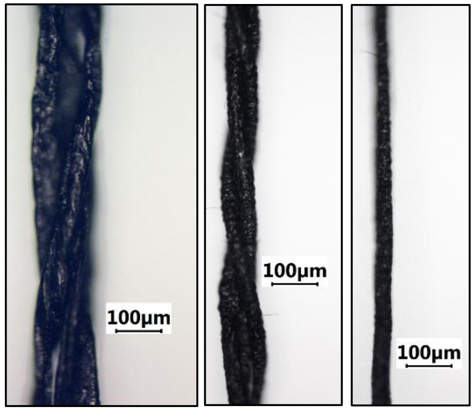
CNT in Li-Ion Batteries

Fabricated pouch cells exceed 250 Wh/kg and will serve as drop-in replacement for Clyde Space batteries (100-150 Wh/kg)



CNT Conductive Wiring

Fabricated Braided Metal Free CNT wires to compare against commercial interconnects



Approach to Integrating Nanoenhanced Components

Characterize SOA CubeSat power system components

Fabricate power system components which incorporate nanomaterials

Replace commercial devices with nanoenhanced versions

Characterize CubeSat power system components and make necessary changes

Integrate finished components into CubeSat power system. Test under space conditions

www.clyde.space

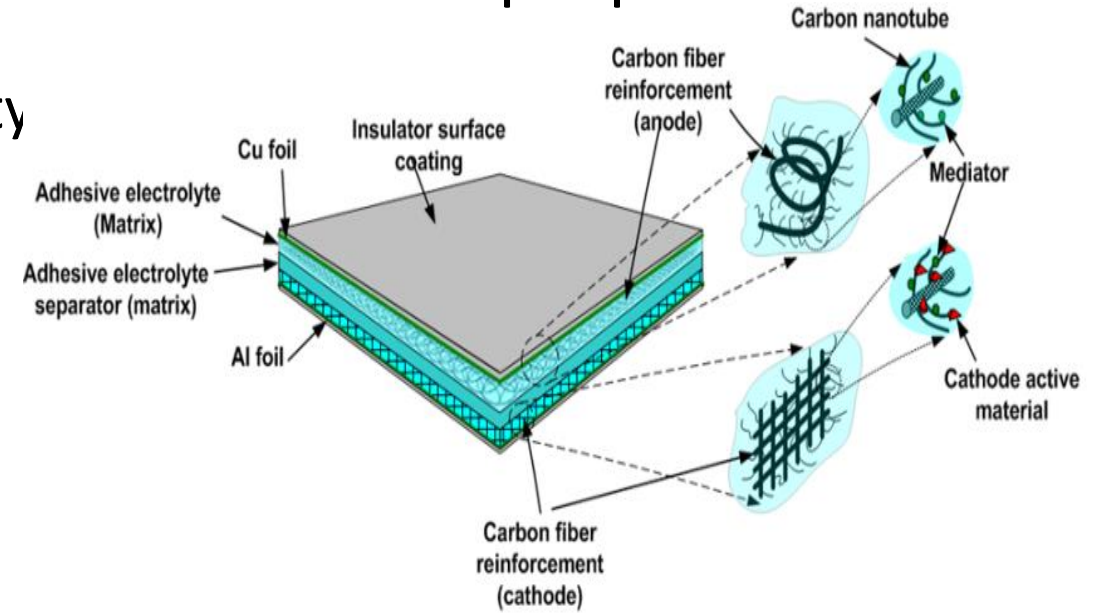
Nano Enhanced

Benefit of enhancing existing technologies through the use of nanomaterials is that the enhanced products can serve as drop in replacements to existing infrastructure, minimizing the need for new equipment and infrastructure.

Development of Lightweight CubeSat with Multifunctional Structural Battery/Supercapacitor Systems

- Lightweight 1U CubeSat which utilizes fully integrated structural battery materials for mission life extension of 200-300%, larger payload capability and significantly reduced mass of 15% or more.
- Mediator-enabled electrolytic polymer
  - ✓ Lightweight load bearing structure and an electrochemical battery system
  - ✓ High specific power and energy with fast charge rate
  - ✓ Significant weight saving
  - ✓ Increase in available volume for payloads

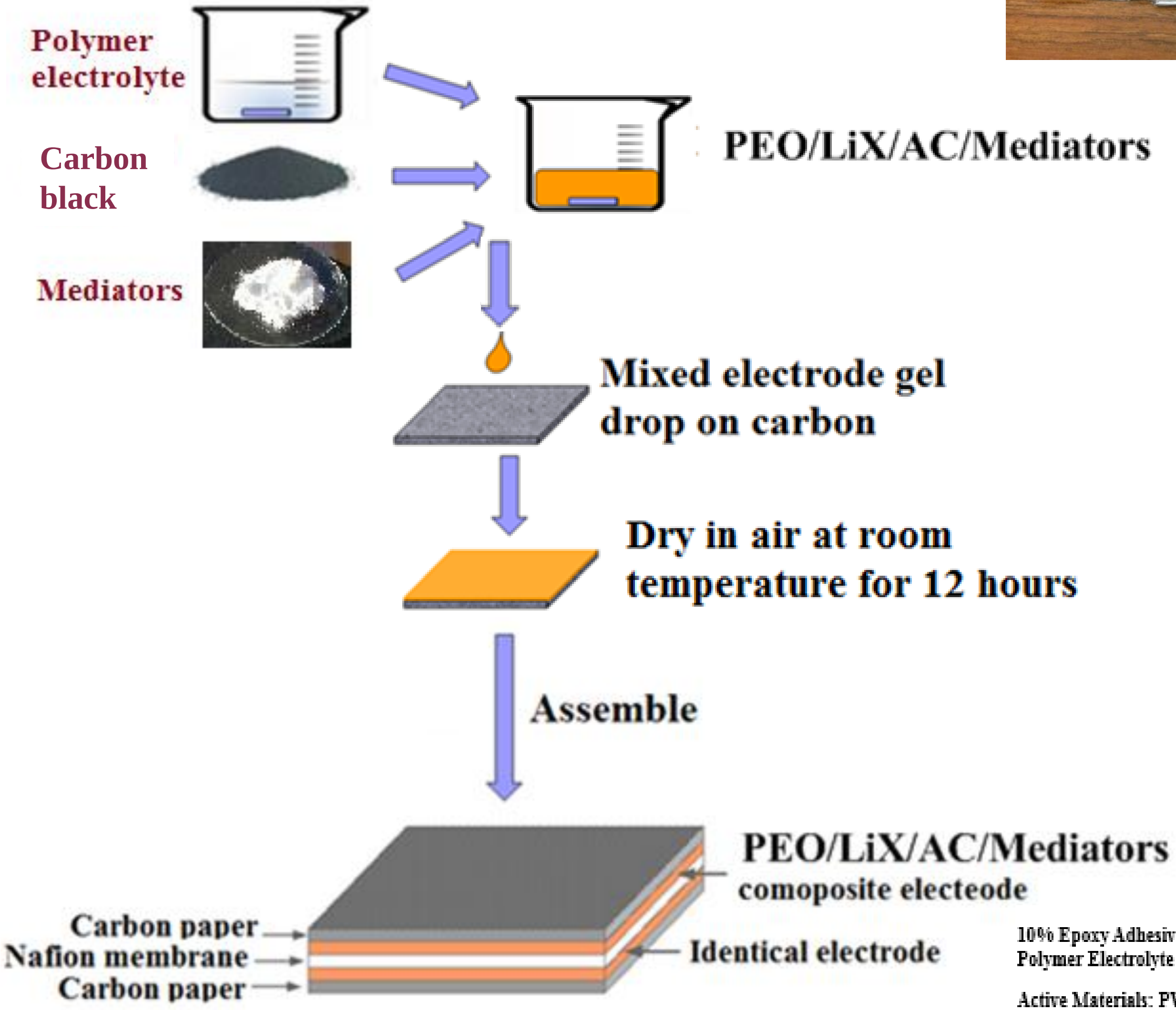
Structural Supercapacitor



***Advancements* in structural battery technology can replace parasitic structural mass with material that provides additional energy, leading to lighter weigh and extended satellite mission life.**

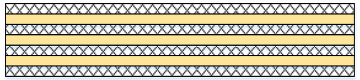
Progress to Date

Supercapacitor Fabrication

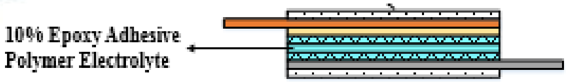


All Solid-State mediator structural supercapacitor stacks

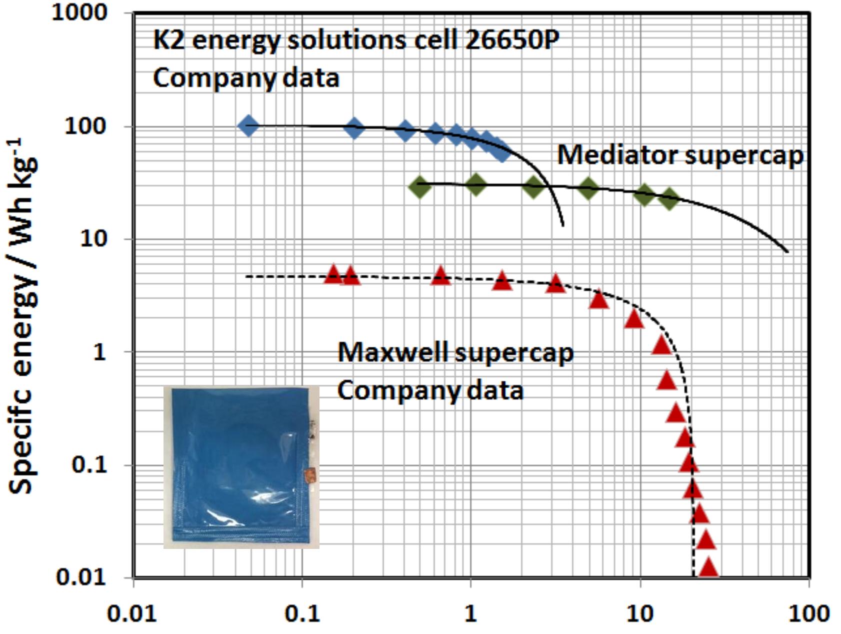
Baseline

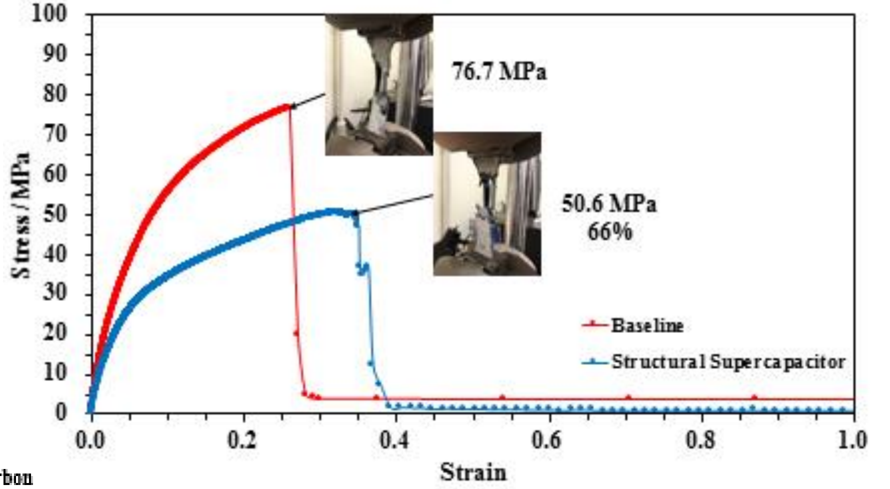


Structural



Active Materials: PVDF+LiTFS+Activated Carbon+Conductive Carbon





Advanced Electrical Bus (ALBus) CubeSat Technology Demonstration Mission

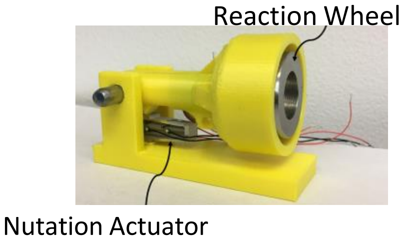
- Provide 100 W capable power management system
- Demonstrate regulated high power bus
- On-orbit demonstration of technologies required for 100 W system
- Power system efficiency ≥ 85%
- EPS shall fit in 1U volume (10x10x10 cm)or less
- CubeSat shall not exceed 4.0 kg mass
- Exhibit solar array mechanisms utilizing shape memory alloy materials

Advanced Electrical Bus (ALBus) CubeSat Technology Demonstration Mission

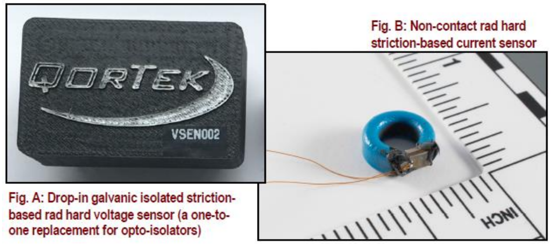
- Images from Katie Oriti?

Power Technologies for SmallSAT

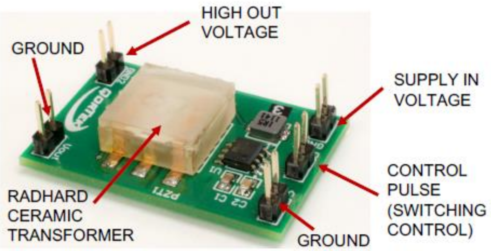
- Power Electronics SBIR work with Qortek:
  - Precision fine attitude tuning of SmallSats (GSFC)
  - Striction based current and voltage sensors for MEO/GEO (GRC)
  - DC/DC conversion – ceramic based power supply for space bus on SmallSats (GRC)
  - Development of SiC and GaN power devices for space applications (GRC with GeneSiC)



Precision Pointing Mechanism



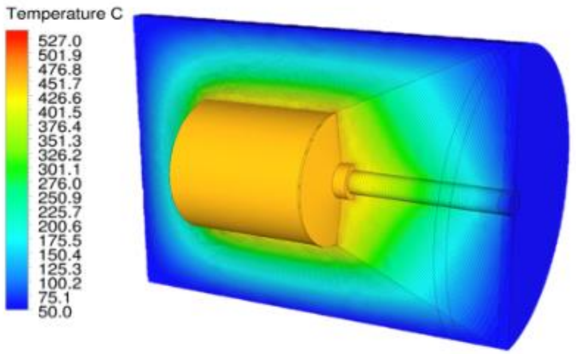
Voltage and Current Sensors



DC/DC Converter

Power Technologies for SmallSAT

- **Super/ultracaps:** In development via GRC SBIRs for power and energy storage
- **Materials:** GRC effort to develop engineering composite materials for high temperature (>300 C) electronic components
- **Power Source:** GRC low power Stirling convertor effort to develop technology for SmallSat applications
- **Testbed:** GRC 28 VDC RSIL testbed developed to test technologies for low power(<450 W) spacecraft



Low Power Stirling Thermal Analysis

RSIL

Acknowledgements

Questions?

R·I·T Wire Comparison Chart

Parameter	Clyde Space Copper Wire	Nanocomp MWCNT Yarn (undoped)	Nanocomp MWCNT Yarn (KAuBr4 doped)	RIT Laser Produced SWCNT (CSA doped)
Resistance/Length (Ohm/m)	3.25	300	70	123
Mass/Length (tex)	2060	12	12	4
Specific Conductivity (S m^2/kg)	6543	284	1110	2000
# strands to match Clyde Space wire R/L	N/A	92	22	38
# Strands to match 20 AWG equivalent diameter	N/A	10 - 11	10 - 11	30