

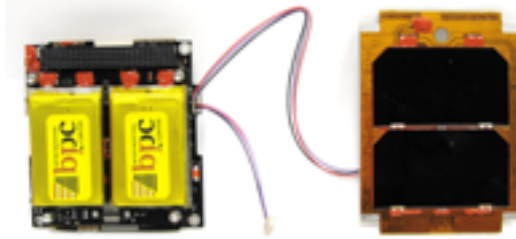
# Demonstration of a Nano-Enabled Space Power System

## Nanomaterial Integration to Provide an Advantage in Power Systems

The Nano-Enabled Space Power System will demonstrate power systems with nanomaterial-enhanced components as a replacement for CubeSat power generation, transmission, and storage (demonstrated in Figure 1). Successful flights of these nano-power systems will accelerate the use of this revolutionary technology in the aerospace industry. The use of nanomaterials in solar cells, wire harnesses, and lithium ion batteries can increase the device performance without significantly altering the device's physical dimensions or the device's operating range (temperature, voltage, current). In many cases, the use of nanomaterials widens the viable range of operating conditions, such as increased depth of discharge of lithium ion batteries, tunable bandgaps in solar cells, and increased flexure tolerance of wire harnesses.

This project will demonstrate the ability of nanomaterial components to reduce weight while maintaining or increasing capability of power systems in four key areas:

1. Power generation: incorporating nanometer sized materials with quantum confined energy levels such as quantum wells (QW) or quantum dots (QD) will better match the effective solar cell bandgap with the specific solar spectrum to achieve higher efficiency. Previous work has focused on spectrally "tuning" the cell of a conventional triple junction solar cell to a more favorable bandgap leading to higher short-circuit current densities in QD-enhanced devices. In addition, new QD solar cell growth techniques have resulted in higher QD material quality and high open circuit voltage ( $V_{oc}$ ). QD cells have



*Figure 1. Small satellite power system to be modified to contain nano-enhanced solar cells, wiring, and batteries produced at Rochester Institute of Technology.*

been demonstrated by the NanoPower Research Lab (NPRL) at Rochester Institute of Technology (RIT) with an absolute air mass zero (AM0) efficiency improvement of 0.5%. In addition, the incorporation of QD cells has shown an increased radiation tolerance over baseline cells, which extends operational lifetime.

2. Power transmission: having metal-free conductors made from 100% carbon nanotubes (CNT) (Figure 2b) provide highly conductive and lightweight power and data transmission connections. This has the potential to reduce the mass of electrical wiring by as much as 50% as compared to copper. The CNT power and data cables developed in the NPRL, have exhibited high electrical conductivity. The capability of metal-free CNT cables have been demonstrated in several different form factors including power cables, USB cables, Ethernet CAT5e, coaxial cables, and radio frequency (RF) antennas.

3. Power storage: integrating CNT into lithium-ion batteries (Figure 2c) increases available energy density. Free-standing CNT electrodes have been shown to be a

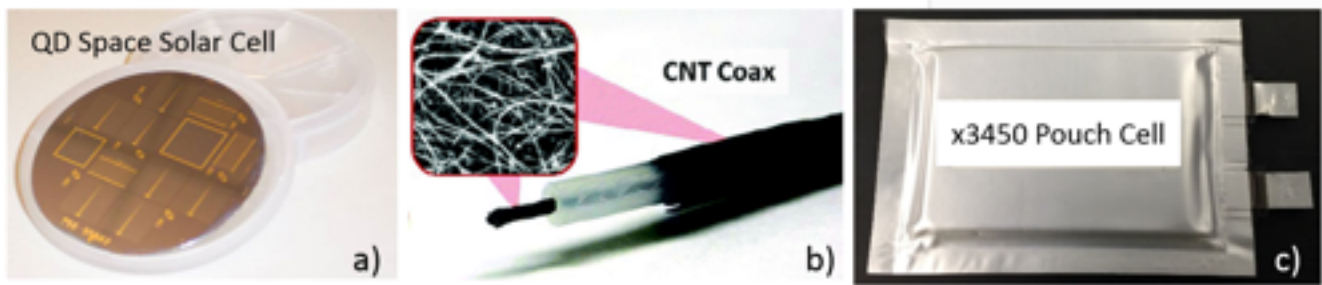


Figure 2. Photographs of nano-enhanced a) quantum dot solar cells, b) carbon nanotubes conductive wiring, and c) x3450 carbon nanotube enhanced lithium ion pouch cell.

suitable light-weight current collector to effectively incorporate silicon (Si) and/or germanium (Ge) nanoparticles as a novel high capacity-high power anode. Recent work has investigated the necessary material parameters that can lead to efficient charge transfer and nanoporosity to accommodate Si/Ge crystalline expansion. Lithium ion batteries fabricated in NPRL utilizing advancements in single-walled carbon nanotubes (SWCNT) and Si/Ge materials have exceeded 300 watt hours per kilogram (Wh/kg) representing a significant increase in energy density over the state of the art (SOA) which range from 100-150 Wh/kg.

4. Power harvesting and heat management: thermo-electric (TE) devices can be made through chemical doping of carbon nanotube materials into both negative and positive type, resulting in a junction capable of generating a current across a temperature gradient. The properties of these CNTs make them excellent candidates for a new generation of light weight TE devices that can be used to absorb excess heat from the back side of solar cells, boosting the overall efficiency of photon to electricity conversion at significant weight savings to typical commercial TE materials.

These evolutionary advancements in each technology can translate into revolutionary changes at the system level for large-scale space deployment by NASA. A critical step along that revolutionary path is demonstration of the technology on board a CubeSat deployment to help accelerate qualification for space missions. These technologies further push the limits of power systems which can be utilized in countless applications from extreme environment monitoring equipment, to internet-of-things, to electric vehicles.

The Nano-Enabled Space Power System project is led by the NPRL at RIT in partnership with NASA Glenn Research Center (GRC).

The Nano-Enabled Space Power System project is managed and funded by the Small Spacecraft Technology Program (SSTP) within the Space Technology Mission Directorate. The SSTP expands U.S. capability to execute unique missions through rapid development and in space demonstration of capabilities for small spacecraft applicable to exploration, science, and the commercial space sector. The SSTP will enable new mission architectures through the use of small spacecraft with goals to expand their reach to new destinations, and challenging new environments.

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**For more information on Nano-Enabled Space Power System, contact:**

Ryne Raffaele  
 Vice President of Research RIT  
 Nano-Enabled Space Power System  
 Project Manager  
 Rochester Institute of Technology  
[rprsp@rit.edu](mailto:rprsp@rit.edu)

Roger C. Hunter  
 Small Spacecraft Technology  
 Program Manager  
 Space Technology Mission Directorate  
 NASA Ames Research Center  
[Roger.C.Hunter@nasa.gov](mailto:Roger.C.Hunter@nasa.gov)

Christopher Baker  
 Small Spacecraft Technology  
 Program Executive  
 Space Technology Mission Directorate  
 NASA Headquarters  
[Christopher.E.Baker@nasa.gov](mailto:Christopher.E.Baker@nasa.gov)

National Aeronautics and Space Administration  
**Ames Research Center**  
 Moffett Field, CA 94035

[www.nasa.gov](http://www.nasa.gov)

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