

# Nanoelectric Materials Laboratory Development

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## Sponsoring Program(s)

Human Exploration and Operations Mission Directorate  
Space Launch System Advanced Development, Spacecraft/Payload Integration & Evolution/Advanced Development, Space Launch System Booster, Center Innovation Funding, Technical Excellence

## Project Description

The Ultracapacitor Research and Development project is a collaborative effort between the NASA Marshall Space Flight Center's (MSFC's) ES43 Parts, Packaging, and Fabrication Branch and the EM41 Nonmetallic Materials Branch. NASA's Ultracapacitor Research is an effort to develop solid-state energy storage devices through processing of ceramic materials into printable dielectric inks, which can be formed and treated to produce solid state ultracapacitor cells capable of exceeding lithium-ion battery energy density at a fraction of the weight.

Research and development efforts into solid state ultracapacitors have highlighted a series of technical challenges such as understanding as-received nature of ceramic powders, treatment and optimization of ceramic powders, dielectric and conductor ink formulation, and firing of printed (green) ultracapacitor cells.

Two facilities have been continually developed since project inception: the Additive Electronics Lab in Bldg. 4487 and the Nanoelectric Materials Lab in Bldg. 4602. The Nanoelectric Materials Lab has become a unique facility at MSFC, capable of custom processing a wide range of media for additive electronics.



Nanoelectric Materials Lab in Bldg. 4602.

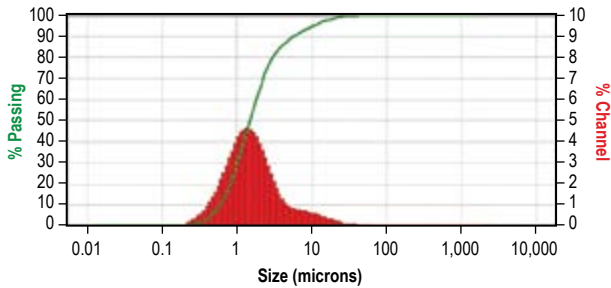


Vibratory mill and control system.

As research has progressed, it was discovered that additional in-house processing was necessary to achieve smaller, more uniform particle diameters.

A vibratory mill was obtained that can agitate powder and media in three directions, which has shown to be much more effective than ball milling. However, in order to understand the effects of milling, a particle size analysis system has been installed to characterize as-received and milled materials.

Continued research into the ultracapacitor technology included advanced milling and optimization of ceramic nanoparticles, fluidized bed treatment of atomic-layer deposition- (ALD-) coated ceramic particles, custom development of dielectric and conductor inks, as well as custom ink precursors such as polyvinylidene difluoride- (PVDF-) loaded vehicles. Experiments with graphene-based inks were also conducted.



**Particle size analysis output—both mean and standard deviation are critical to producing high capacitance inks.**

### *Anticipated Benefits*

Solid state ultracapacitors are completely safe, posing no risk to crew, vehicle, or mission. These ultracapacitors are also capable of rapid charge and discharge, and experience no notable energy leakage. Moreover, solid state ultracapacitors will demonstrate drastic weight savings over electrochemical batteries.

Growing expertise in particle size analysis can be of great use to other research efforts, namely nuclear thermal propulsion (fuel development) and additive manufacturing (particle size has a large impact on manufactured parts).

Expanded capabilities in creating custom ink formulations opens the door to a variety of additive electronics research avenues. For example, the same capabilities can be used to research and develop electroluminescence.

### *Potential Applications*

Potential applications include range safety batteries for the booster, core stage, and exploration stages; short-window solar energy capture for orbital satellites (CubeSats); ground-based applications are wide ranging—electric vehicles, directed energy devices, grid

leveling, residential power, and hand-held electronics; and 3D circuit printing could provide tailored energy storage and integration into circuit boards.

## **Notable Accomplishments**

A fluidized bed reactor was used to dramatically improve treatment of ALD-coated ceramic powders. Trivalent doping of perovskite ceramic nanoparticles showed a significant increase in dielectric properties, achieving capacitances in the microFarad range with 30-micron-thickness ultracapacitor devices. Vibratory milling of ceramic powders has shown dramatic decrease in particle size distribution, translating to increased density of the dielectrics and an increase in capacitance. Novel and unique dielectric inks have been developed for both high temperature with glass binders and low temperature with composite polymer-ceramics. Novel and unique conductor inks have been developed for use in ultracapacitors and 3D circuit printing.

## **References**

Allen, L.: “Solid State Ultracapacitor to Replace Batteries,” Marshall Technology Exposition, NASA Marshall Space Flight Center, Huntsville, AL, October 27, 2014.