



NASA MSFC Materials & Process Development Flexible Sensing Technology



IEEE SoutheastCon 2019

Materials & Process Development for Printable Electronics at MSFC

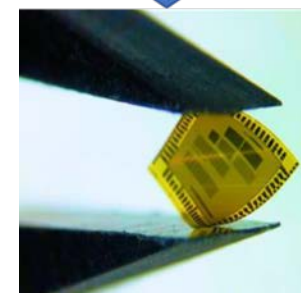
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NASA MSFC
EM42/ESSCA



Background and requirement

ISM Multi Material Fabrication Key Areas:

- **Development of Flexible Sensing Technology:**
 - Development of next-generation flexible sensor platforms and printed sensors for Astronaut Crew Health Monitoring on International Space Station.
 - Development of materials and processes for printed sensors.
 - Evaluation and incorporation of new component technologies (flexible components, wireless communications, etc.)
- **Energy Storage Technology Development:**
 - Develop triboelectric power in order to build a self-contained sensor system.
 - Further maturation of an all-printed supercapacitor.
 - Developing very high energy density supercapacitors for battery replacement with several commercial companies.
 - Developed an Al-air battery with University of Tennessee & ORNL for scalable battery replacement applications.



**Flexible
Electronics
Sensors**



NASA MSFC Materials & Process Development Background on In Space Manufacturing

ISM Objective: Develop and enable the technologies, materials, and processes required to provide sustainable on-demand manufacturing, recycling, and repair during Exploration missions.

❖ **In-Space Manufacturing Technology & Material Development:** Work with industry and academia to develop on-demand manufacturing and repair technologies for in-space applications.



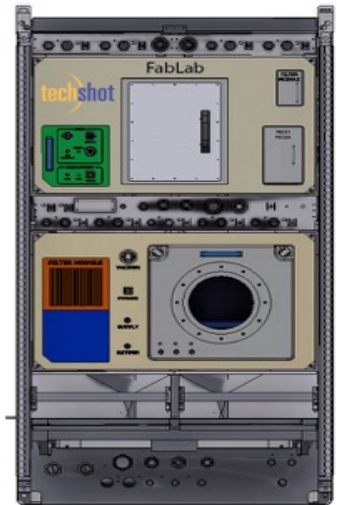
Made in Space, Inc. ISS Additive Manufacturing Facility (AMF)

❖ **In-Space Recycling & Reuse Technology & Material Development:** Work with Industry and academia to develop recycling & reuse capabilities to increase mission sustainability.



ISS Refabricator Demo with Tethers Unlimited, Inc.

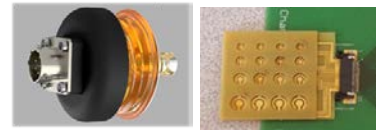
❖ **In-Space Manufacturing Digital Design & Verification Database (i.e. WHAT we need to make):** ISM is working with Exploration System Designers to develop the ISM database of parts/systems to be manufactured on spaceflight missions.



NextSTEP Multi-material 'FabLab' Private Public Partnership



Design Database Development Printed Life Support System (LSS) Retaining Plate (Left); Urine Funnels (Right)



Printed Electronics: LSS Pressure Switch (Left); UV Radiation Sensor (Right)



Collaborative Leveraging with Industry and Academia



NASA MSFC Materials & Process Development Laboratory Capabilities

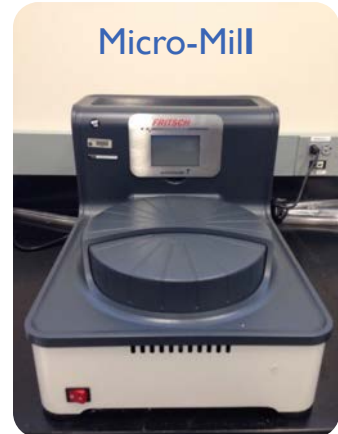


Nanomaterials Development & Processing

Powder Processing



Vibratory Mill



Micro-Mill



Fluidized Bed Furnace

Ceramic Powder Processing

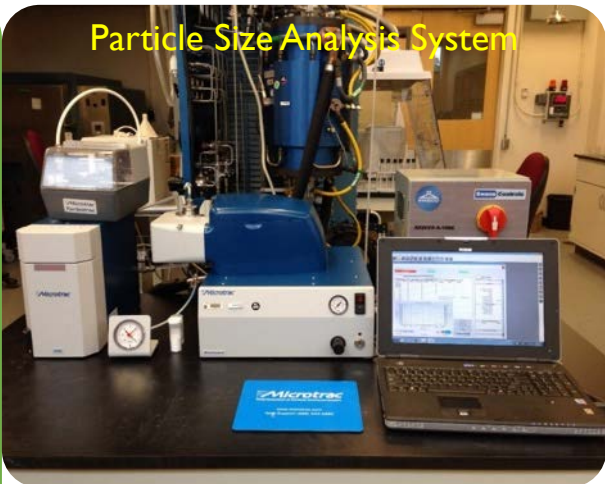
- Powders can be reduced in sized and homogenized
 - Vibratory Mill utilizes 3-axes grinding action
 - Micro-mill provides fast-grinding for small batches, and can achieve < 50nm particle sizes
- Powder treatment with forming gas inside fluidized bed furnace produces desired dielectric properties for ultracapacitors
 - Current process is DOE-optimized

Particle Size Analyses

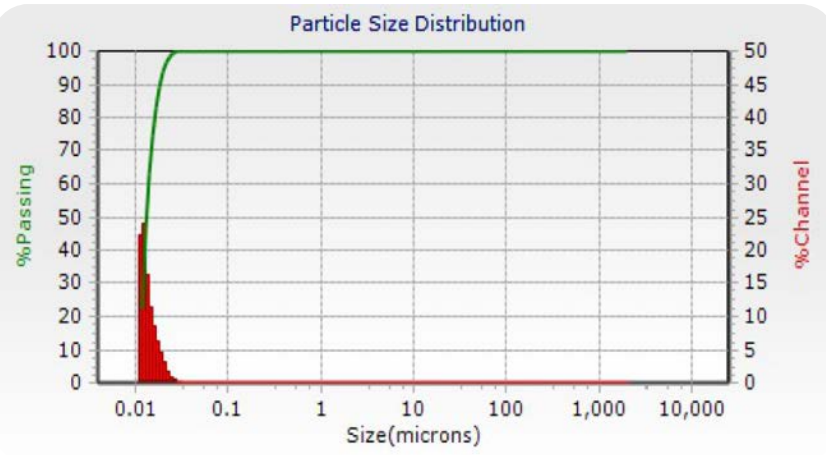
Particle Size Measurements

Understanding of mean particle size and distribution aids in powder milling for uniform sizing.

Sample preparation is critical in gathering accurate data, as data collection (air bubbles can skew results dramatically).



Particle Size Analysis System

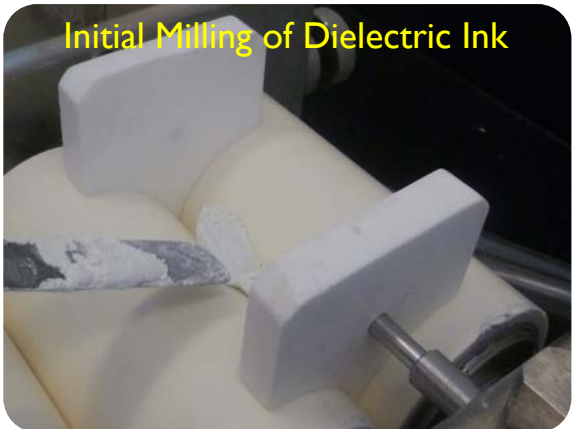




NASA MSFC Materials & Process Development Laboratory Capabilities

Nanoinks Development & Processing

Ink Formulation



Ink Formulation

- The combination of ceramic (dielectric) or metallic (conductor) powders with vehicles, dispersants, and other additives creates **inks** which can be printed with a variety of different deposition processes.
- **Thick film ink** formulations are produced via 3-roll mills, which disperse particles throughout the mixture via a combination of compression and shear between tightly spaced rollers. Roller speed and spacing are both controllable and are key factors in the final product.
- **Thin film** inks require fewer additives (typically the powder material and a vehicle) and are used in direct write deposition systems. Therefore lower viscosity is necessary, which can be achieved using a high-shear dispersion mixer.

Strategic Advantages

- While initially developed to support Ultracapacitor research, capabilities in the Nanoelectric Materials Lab can be used for a variety of research (ultracapacitors, conductor inks, electroluminescence, radio-frequency identification (RFID)).
- Particle Size Analysis system can be used to support many different areas (propellant formulation, additive manufacturing)
- Equipment allows for custom development of raw materials



NASA MSFC Materials & Process Development Laboratory Capabilities

Material processing

3D Multi-Material Printer



nScript 3D Multi-Material Printer

nScript 3D multi material printer

- 4-head capability:
 - SmartPump for inks
 - 2 nFD heads for filament polymers
 - Pick & place head for discrete electronic components.
- High precision 3D deposition in a 300x300x150mm volume. Developing materials and processes leading to a multi material FabLab for International Space Station.
- Currently developing Ag inks for electronics and Al pastes for additive metal manufacturing.

Direct Current Sintering Furnace



Direct Current Sintering Furnace

- Added in 2016 for the further development of high performance ultracapacitor and thermoelectric materials. Initial research was from a collaboration in 2014 at Oak Ridge National Laboratories.
- Ultracapacitor development is high density sintering of coated and doped barium titanate materials. Have achieved >99% density and extremely high permittivity $>1 \times 10^6$
- Thermoelectric research to create high figure of merit n-type & p-type thermoelectrics. Evaluating several potential doped materials and processing parameters.

Direct Current Sintering Furnace



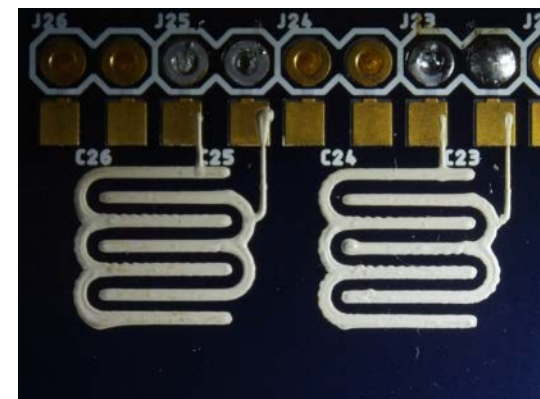
NASA MSFC Materials & Process Development Flexible Sensor Development



Multi Material Fabrication and Materials Development

Development of Flexible Sensing Technology:

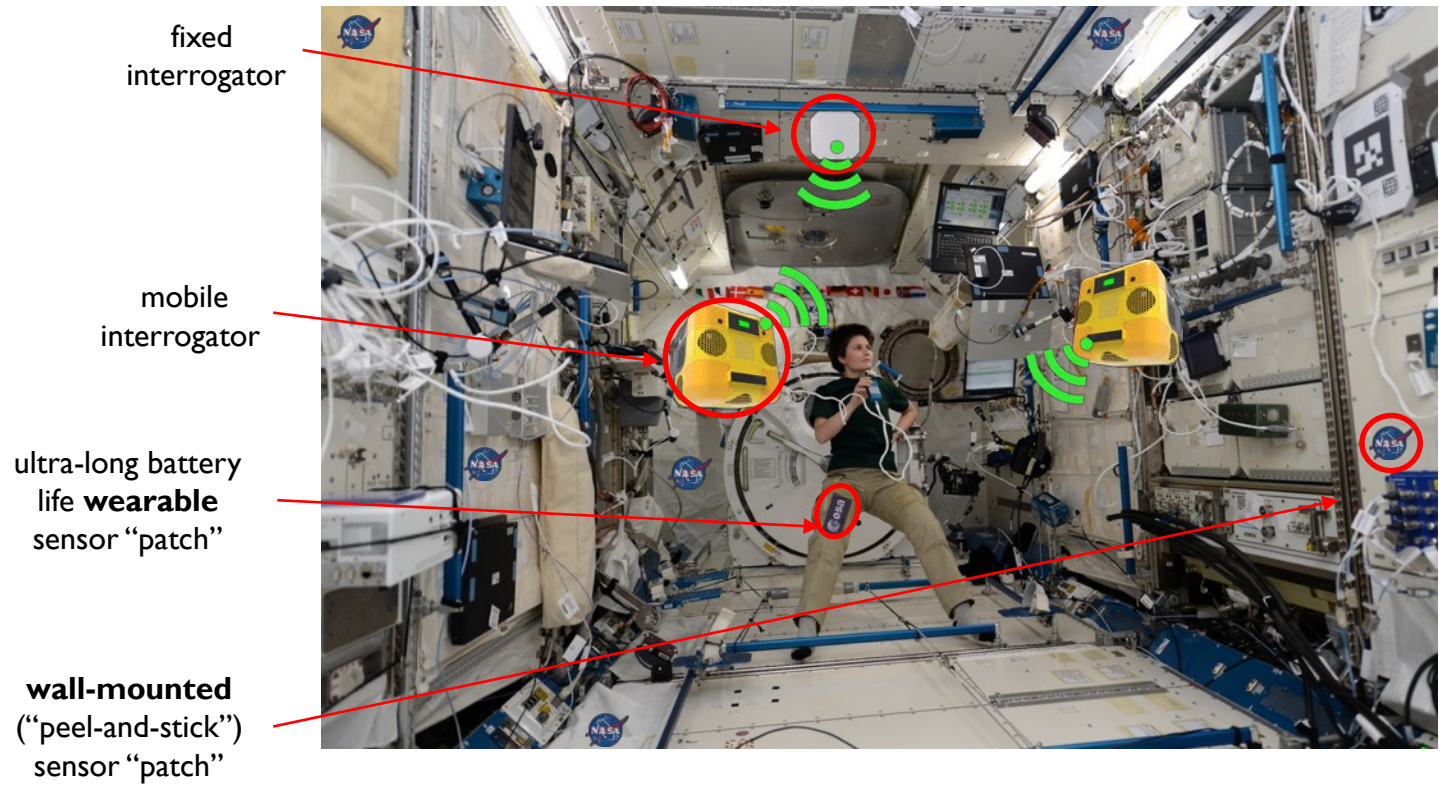
- Development of next-generation wireless flexible sensor platforms and printed sensors for Astronaut Crew Health Monitoring on International Space Station.
- Development of materials and processes for printed sensors.
- Evaluation and incorporation of new component technologies (flexible components, wireless communications, etc.)





NASA MSFC Materials & Process Development Flexible Sensor Development

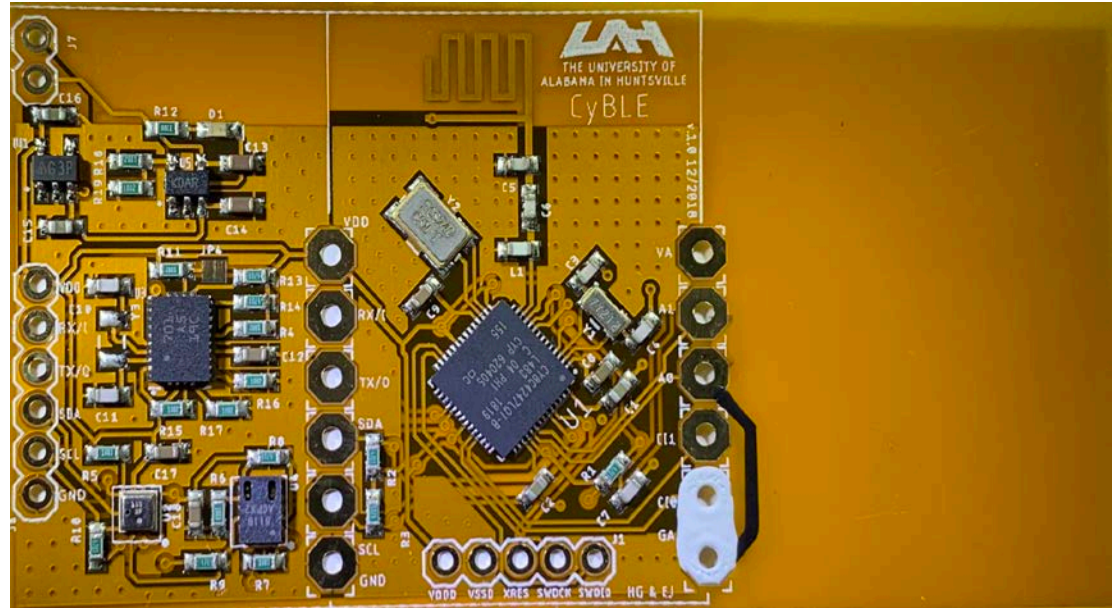
Wearable Wireless Sensors Operational Concept





NASA MSFC Materials & Process Development Next-Generation Flexible Sensor Platforms

First Generation Personal CO₂ Monitors



Flexible Sensor Platform with High Speed BLE Communications with printed thermistor & respiration sensors

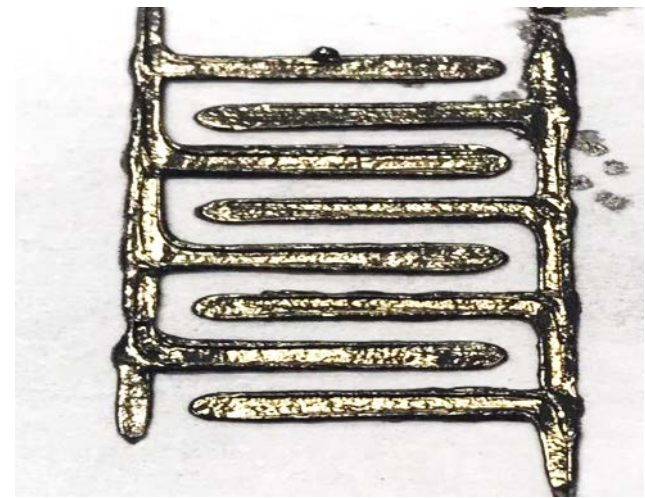


NASA MSFC Materials & Process Development Development of Printed Sensors

First Generation Personal CO₂ Monitors



3D-Printed Al-Fe₃O₂
Nanothermite
Sintered CO₂ Sensor

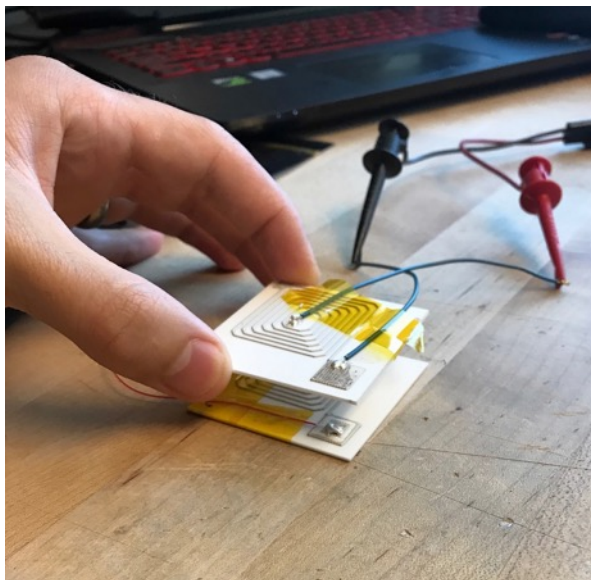




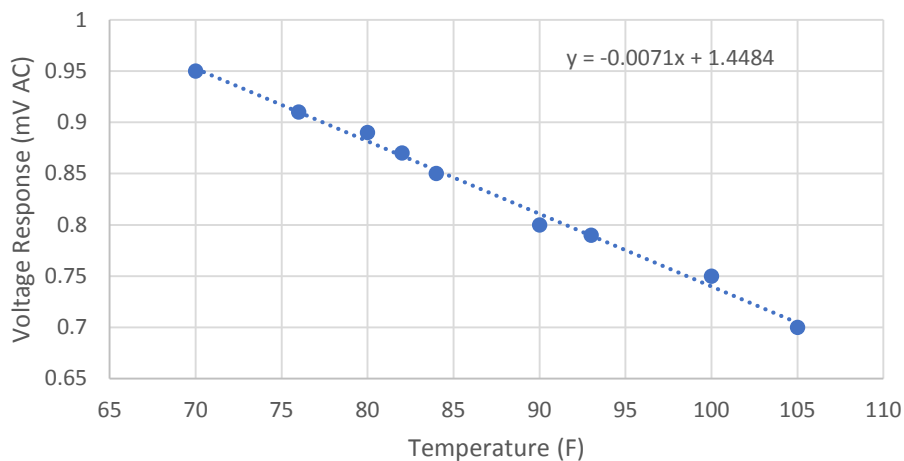
NASA MSFC Materials & Process Development Development of Printed Sensors



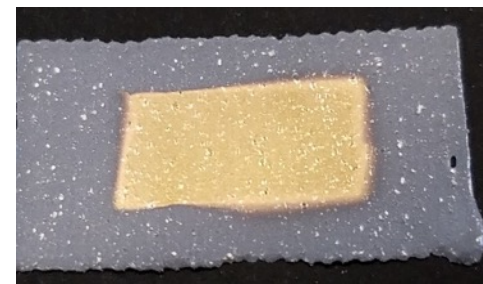
Humidity/Respiration Sensor



Sensor 1 Response to Temperature



Composite Temperature & Pressure Sensor

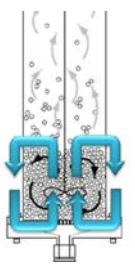




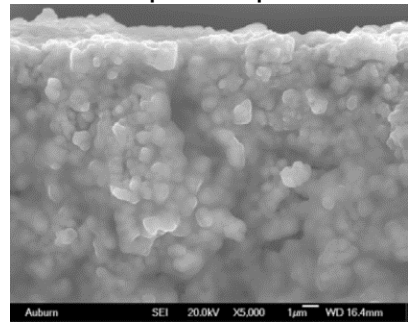
NASA MSFC Materials & Process Development Solid State Ultracapacitor Development

Development of Perovskite Ultracapacitors

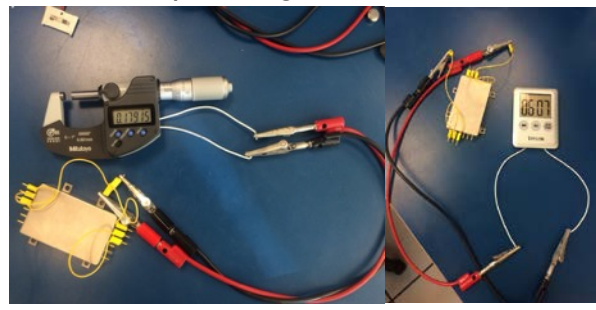
Treatment of perovskite nanoparticles
– pre-milling to low nanometer PC
followed by ALD coating



Final density of doped sample



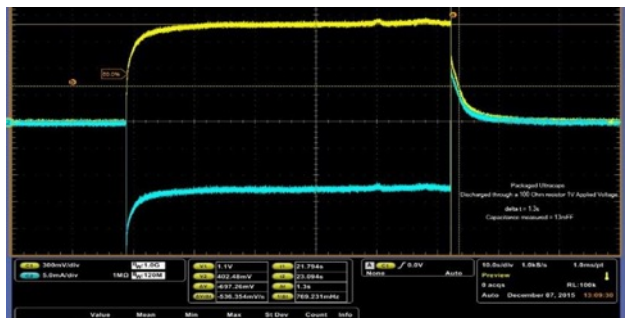
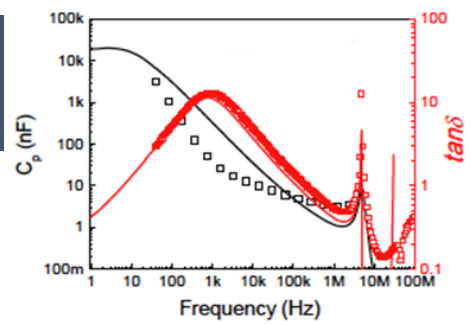
Charged ultracapacitor
powering instruments



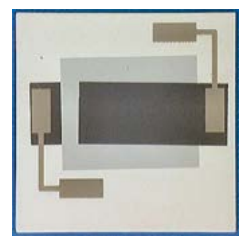
Test fixture for three
devices in parallel



Doped material found to store energy from high capacitance, exhibits high current and discharges energy quickly – benefits customers needing battery/capacitor hybrid energy



Single device discharge – 20 mA





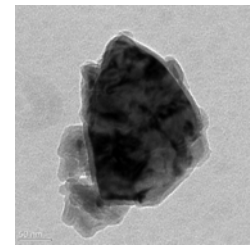
NASA MSFC Materials & Process Development Solid State SPS Supercapacitor Development

Spark Plasma Sintered (SPS) Supercapacitor

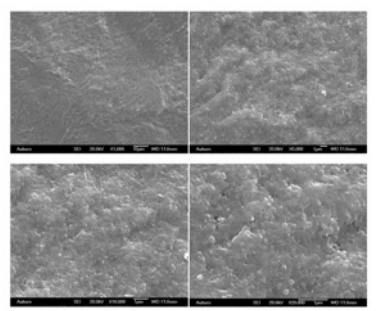
SPS-sintered sample 20mm diameter – density >99%



SPS samples exhibit gigantic permittivity with breakdown voltage up to 500V. Very good potential for very high energy density. Working with commercial companies to package the technology.



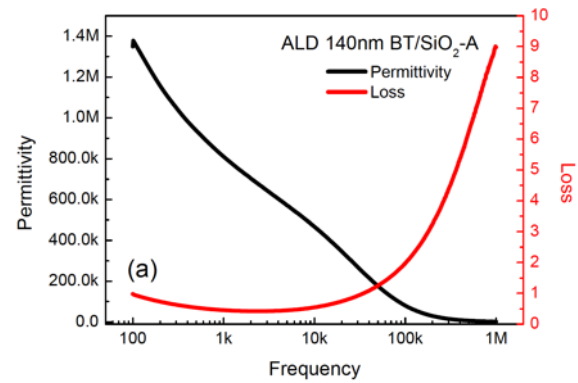
High-resolution TEM image of SiO₂ coated BT, coating thickness 5nm



Cross-section of SPS-sintered BT-140 sample



MSFC Direct Current Sintering Furnace for SPS



Plot of dielectric permittivity and loss for 140nm particle size BT sample