Auburn University Materials Engineering Department

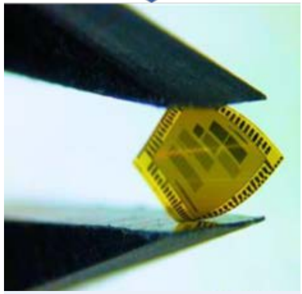
March 25, 2019

NASA MSFC Materials & Process Development
Flexible Sensing Technology

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

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

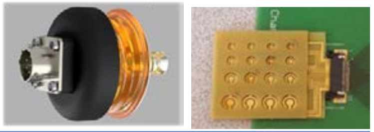
- ***In-Space Manufacturing Technology & Material Development: Work with industry and academia to develop on-demand manufacturing and repair technologies for in-space applications.***
- ***In-Space Recycling & Reuse Technology & Material Development: Work with Industry and academia to develop recycling & reuse capabilities to increase mission sustainability.***
- ***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.***

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

ISS Refabricator Demo with Tethers Unlimited, Inc.

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

Ceramic Powder Processing

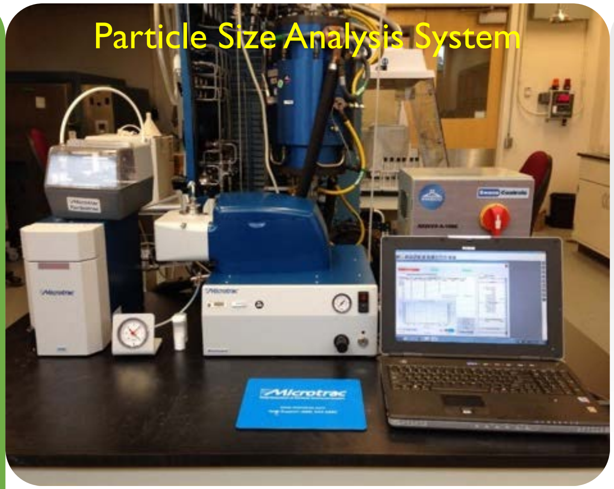
- Powders can be reduced in sized and homogenized
  - Vibratory Mill utilizes 3-axes grinding action
  - Micro-mill provides fast-grinding for small batches, and can achieve < 50nm particle sizes
- Powder treatment with forming gas inside fluidized bed furnace produces desired dielectric properties for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

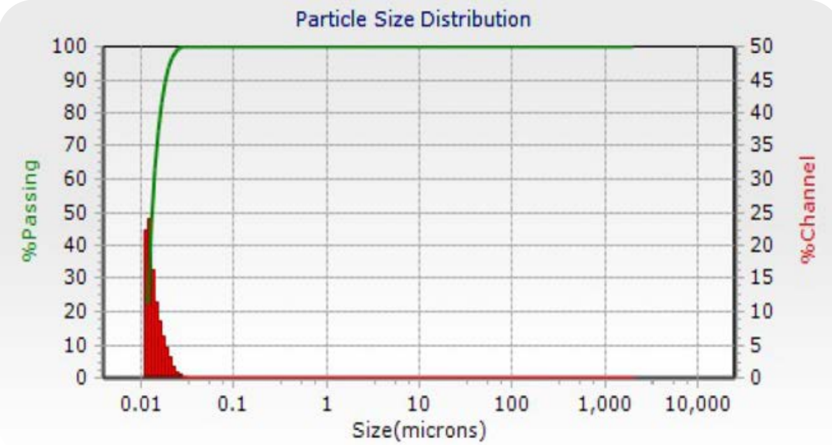
Particle Size Analyses

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).

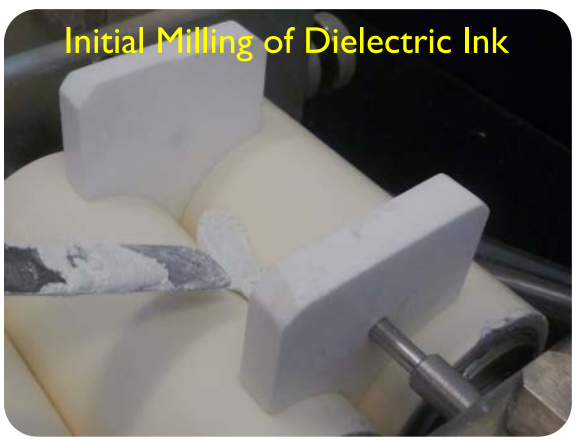


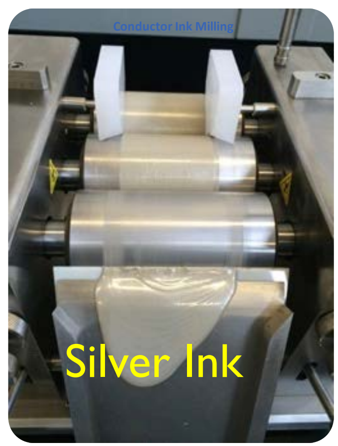


NASA MSFC Materials & Process Development Laboratory Capabilities

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 though out 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 Nanoelctric 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

3D Multi-Material Printer

Material processing

nScrypt 3D Multi-Material Printer

nScrypt 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 $>1x10^6$
- Thermoelectric research to create high figure of merit n-type & p-type thermoelectrics. Evaluating several potential doped materials and processing parameters.

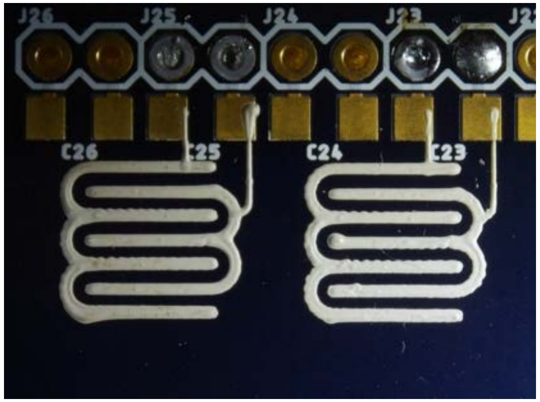
Direct Current Sintering Furnace

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.)



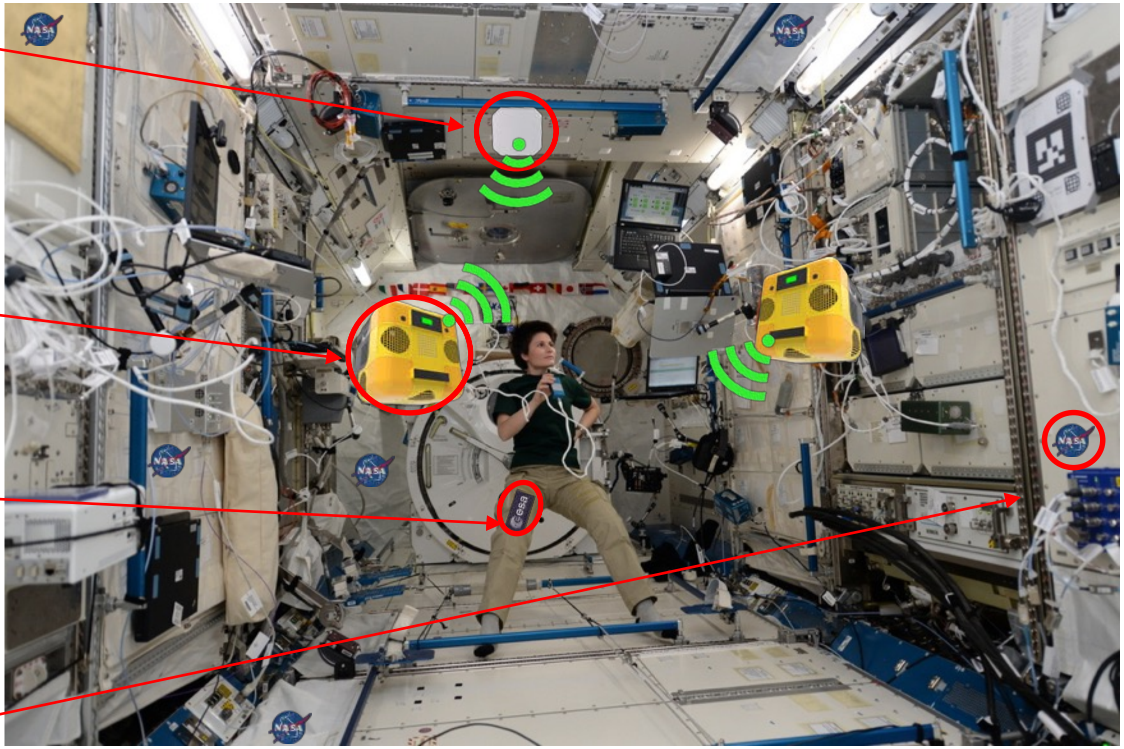
Wearable Wireless Sensors Operational Concept

fixed interrogator

mobile interrogator

ultra-long battery life **wearable** sensor “patch”

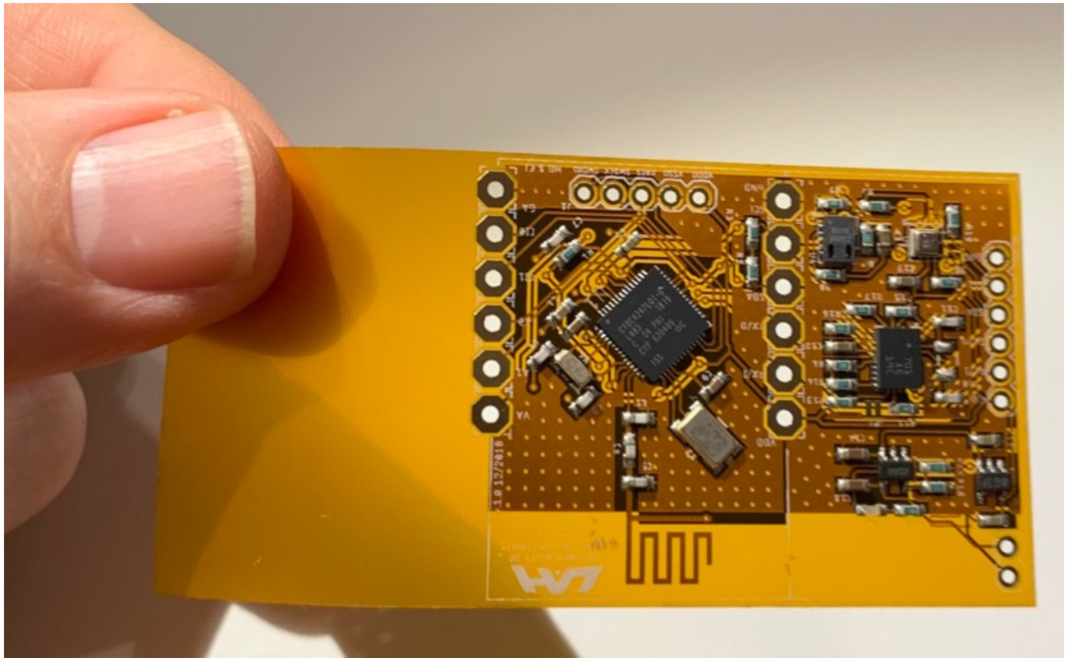
wall-mounted (“peel-and-stick”) sensor “patch”



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

First Generation Personal CO_2 Monitors

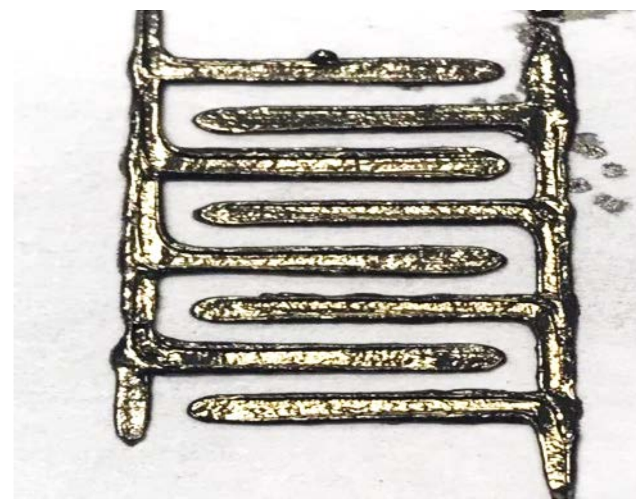
Flexible Sensor Platform with High Speed BLE Communications



NASA MSFC Materials & Process Development
Development of Printed Sensors

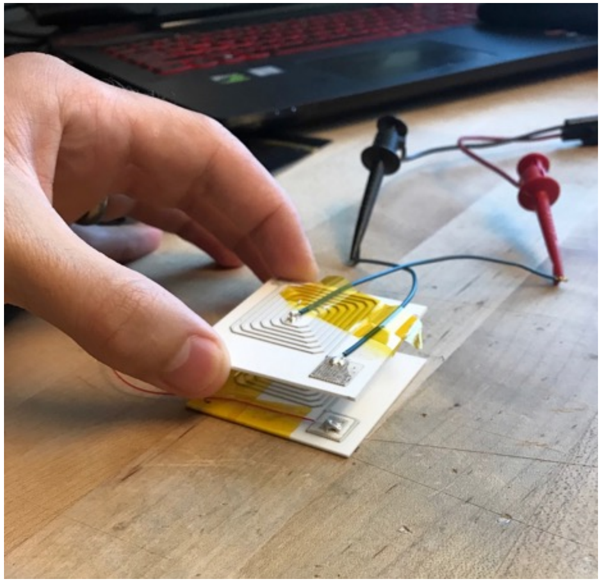
First Generation Personal CO_2 Monitors

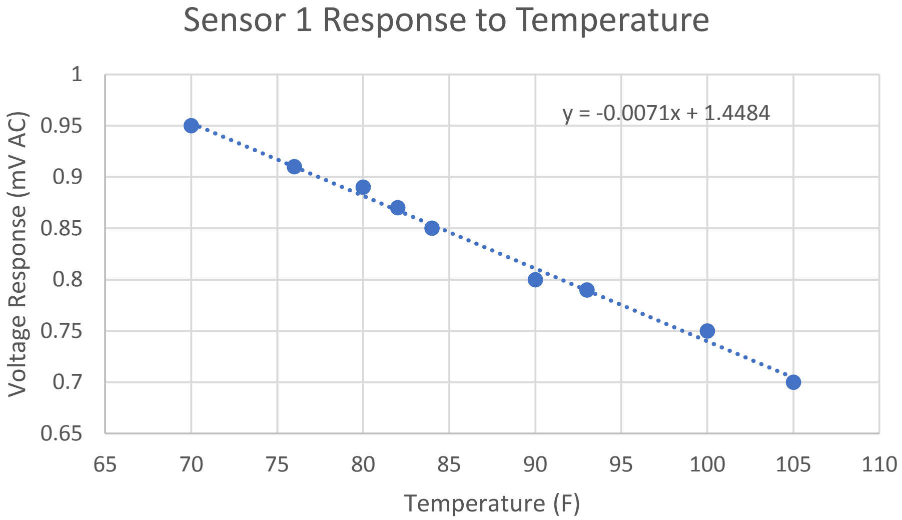
3D-Printed Al-Fe_3O_2
Nanothermite
Sintered CO_2 Sensor



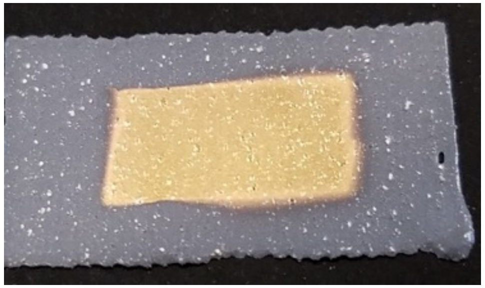
NASA MSFC Materials & Process Development
Development of Printed Sensors

Humidity/Respiration Sensor





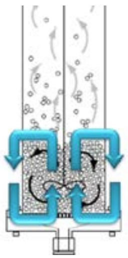
Composite Temperature & Pressure Sensor



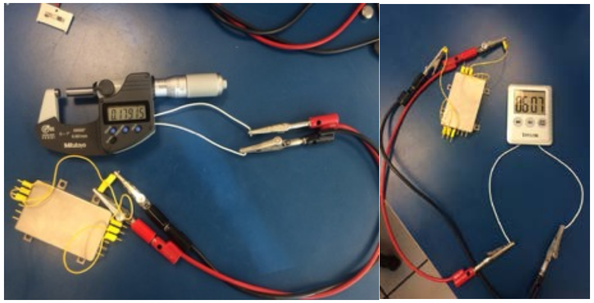
NASA MSFC Materials & Process Development
Solid State Ultracapacitor Development

Development of Perovskite Ultracapacitors

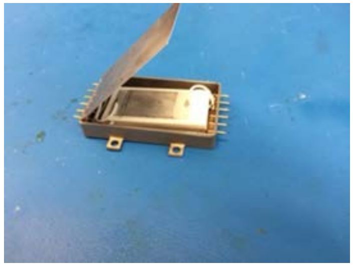
Treatment of perovskite nanoparticles – pre-milling to low nanometer PC followed by ALD coating



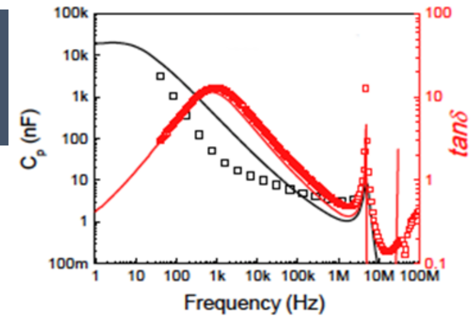
Charged ultracapacitor powering instruments



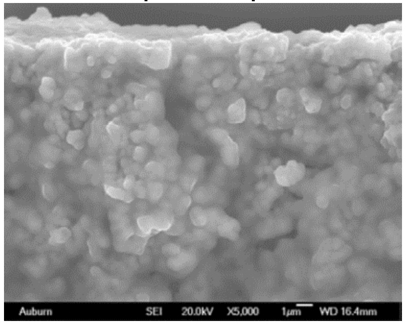
Test fixture for three devices in parallel

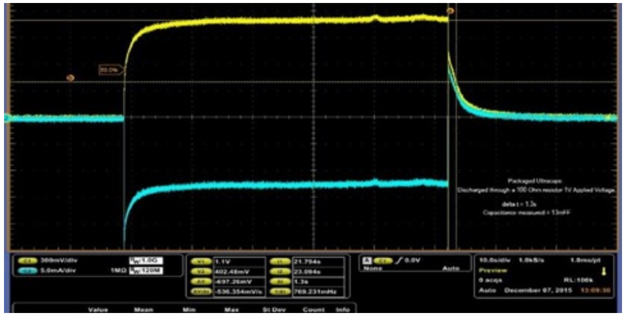


Doped material found to store energy from high capacitance, exhibits high current and discharges energy quickly – benefits customers needing battery/capacitor hybrid energy

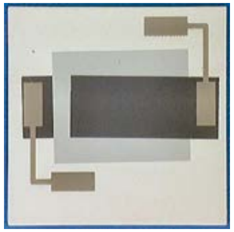


Final density of doped sample





Single device discharge – 20 mA

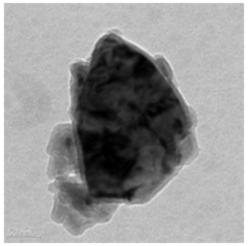


NASA MSFC Materials & Process Development
Solid State SPS Supercapacitor Development

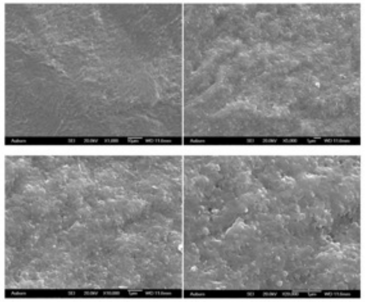
Spark Plasma Sintered (SPS) Supercapacitor

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.

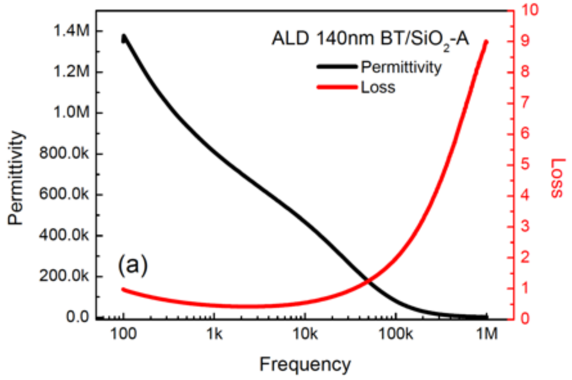


High-resolution TEM image of SiO_2 coated BT, coating thickness 5nm



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