



NASA MSFC In Space Manufacturing Multi Material Fabrication



Flexible Sensor Development for Astronaut Crew Health Monitoring

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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.

- Development of Crew Health Wearable Sensors
- Energy & Power Development

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

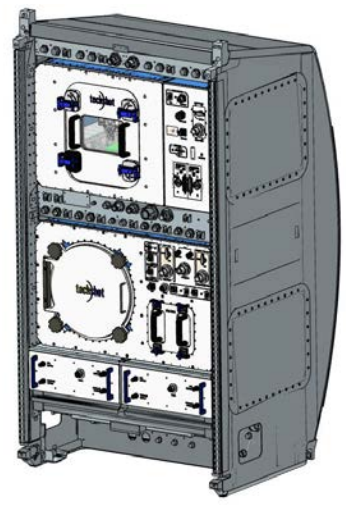
❖ **In-Space Manufacturing Digital Design & Verification Database (i.e. WHAT we need to make):** ISM is working with Exploration System Designers to develop the ISM database of parts/systems to be manufactured on spaceflight missions.



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



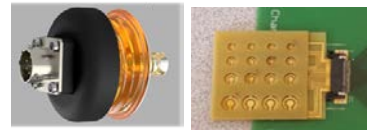
ISS Refabricator Demo with Tethers Unlimited, Inc.



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)



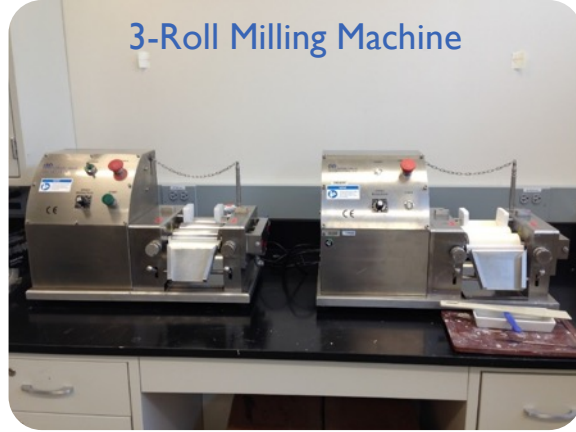
Collaborative Leveraging with Industry and Academia



NASA MSFC Materials & Process Development Laboratory Capabilities

Nanoinks Development & Processing

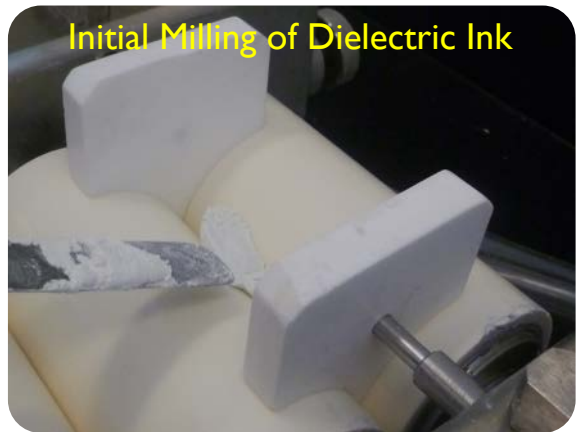
Ink Formulation



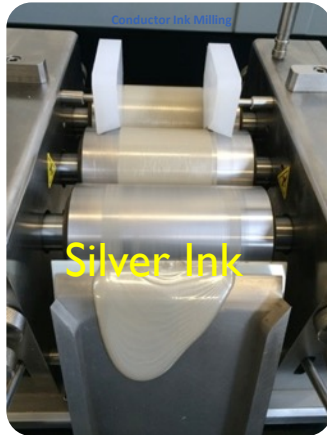
3-Roll Milling Machine



High shear mixer



Initial Milling of Dielectric Ink



Silver Ink

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 through 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

3D Multi-Material Printers

Material processing



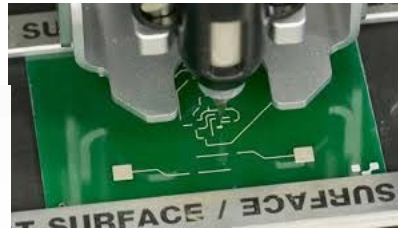
nScript 3D Multi-Material Printer

nScript 3D multi material printer

- 4-head capability:
 - SmartPump for inks
 - 2 nFD heads for filament polymers
 - Pick & place head for discrete electronic components.
 - nMill for polishing, drilling, subtractive processing
- High precision 3D deposition in a 300x300x150mm volume. Developing materials and processes leading to a multi material FabLab for International Space Station.
- Recent addition of a laser sintering capability.



Voltera electronics printer



Voltera Electronics Printer

- Added in 2018 for quick-turnaround prototyping of sensors and testing of inks.
- Printing resolution is good for prototyping and general electrical circuits, but not fine pitch devices or tight line spacing.

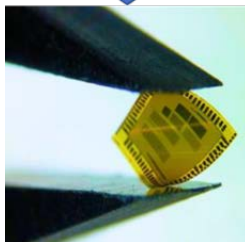


NASA MSFC Materials & Process Development Flexible Sensor Development

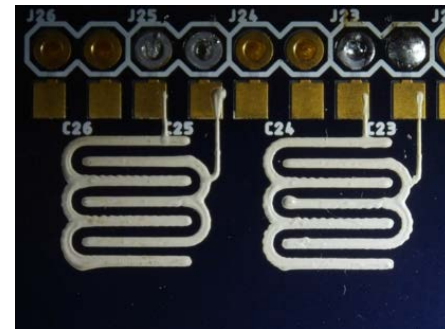
Multi Material Fabrication and Materials Development

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.)



Flexible
Electronics
Sensors



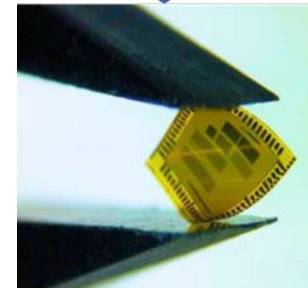
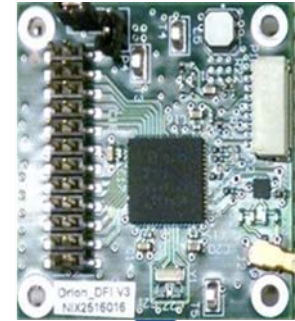


NASA MSFC Materials & Process Development Flexible Sensing Technology

Sensor Development

Development of Flexible Sensing Technology for Crew Health Monitoring:

- Development of next-generation flexible sensor platforms and printed sensors for Crew Health Monitoring on International Space Station.
- Development of materials and processes for on-demand printed sensors. (example, solid state humidity sensor and strain sensor)
- Evaluation and incorporation of new component technologies (flexible components, wireless communications, etc.)
- Development of printed sensors for Structural Health Monitoring applications.
- Development of biosensors for Crew Health physiological monitoring. (examples: cortisol and hydration sensors)
- Investigation of flexible battery systems.



Flexible Electronics Sensors



Printed cortisol sensor



Energy & Power

ISM Multi Material Fabrication Key Areas:

Energy Storage Projects:

- Printed ultracapacitor – coated barrier-layer capacitor
- Printed ultracapacitor – Rare Earth co-doped
- SPS supercapacitor – Spark Plasma Sintered
- Printed supercapacitor – Ames carbon-carbon electrolyte
- Printed supercapacitor – UAH CAN SPS and spin-coated elastomer film
- Printed supercapacitor –PVDF-loaded printed film
- Fabricated supercapacitor – Ionic Liquid Interactions with Functionalized Carbon Nanotubes
- Aluminum-air battery
- Printed battery –high-energy printed battery.

SPS Furnace & Supercapacitor



Printed Supercapacitor

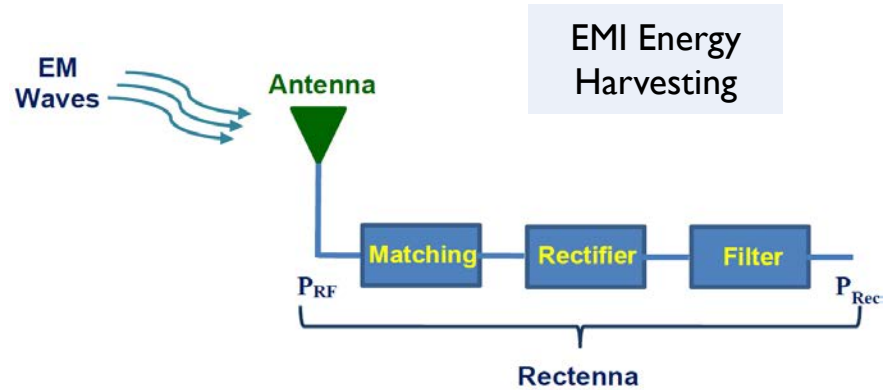
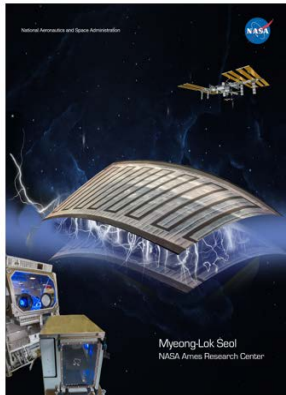
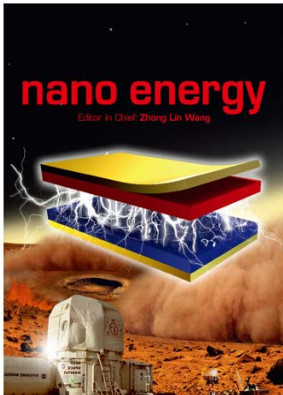


Energy & Power

ISM Multi Material Fabrication Key Areas: Power Generation Projects:

- Thermoelectric development – Research on doped ZnO and other materials with SPS sintered processing
- Thermoelectric development – research on SPS sintered InO₂
- Triboelectric generator development
- Electromagnetic radiation harvesting - “rectenna” printed antenna array.

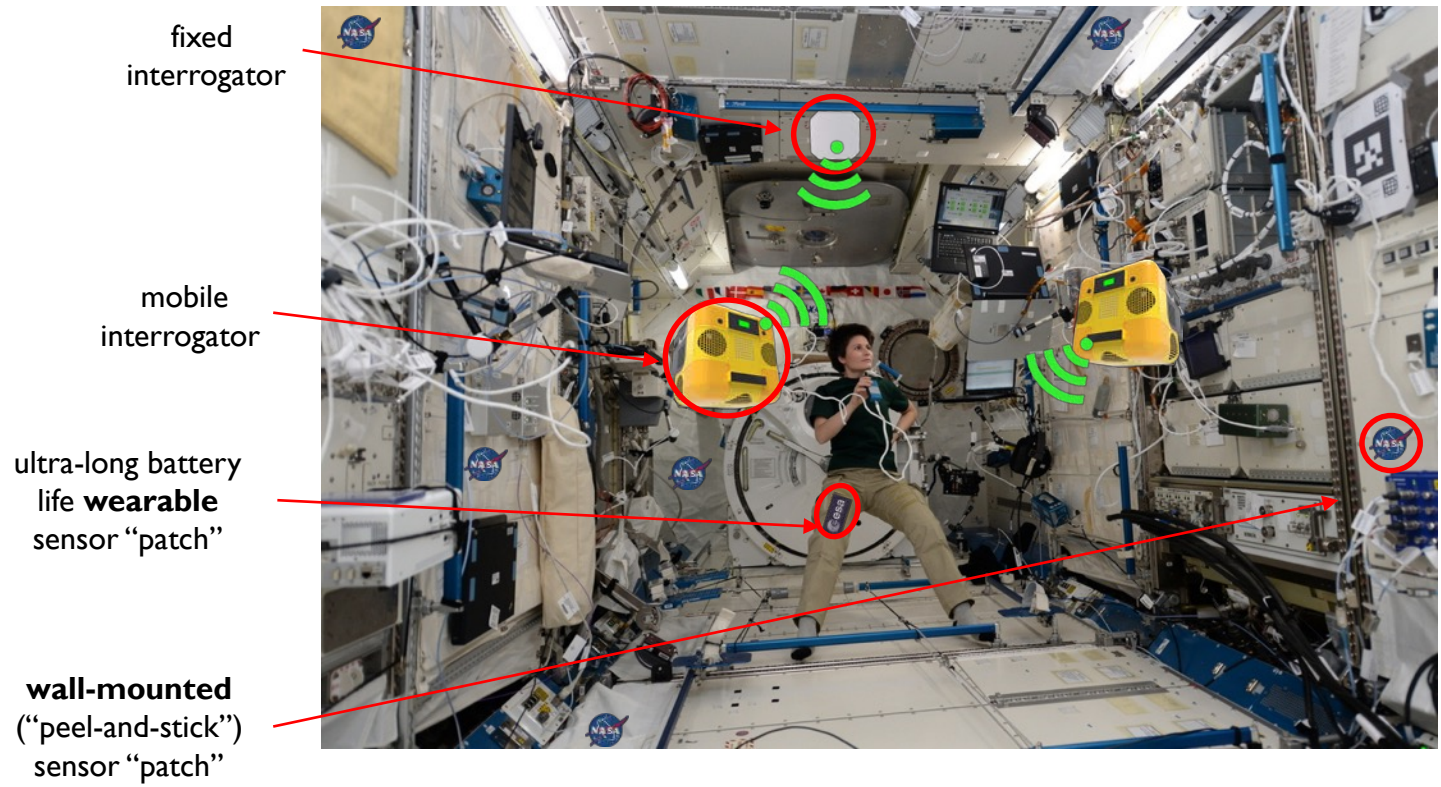
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NASA MSFC Materials & Process Development Flexible Sensor Development

Wearable Wireless Sensors Operational Concept



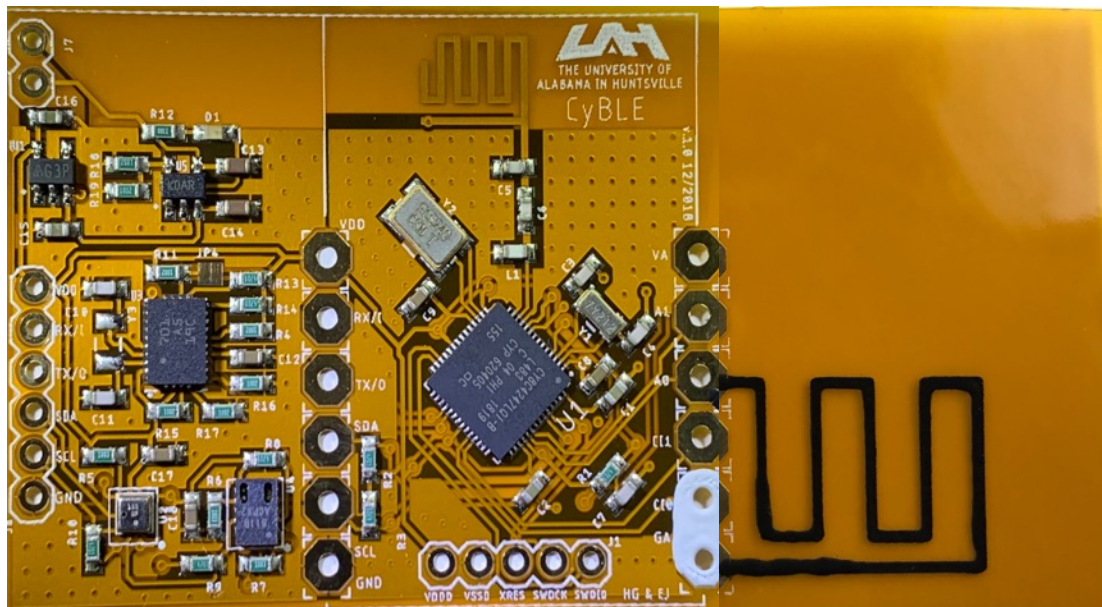


NASA MSFC Materials & Process Development Next-Generation Flexible Sensor Platforms

First Generation Personal CO₂ Monitor



3D-Printed Al-Fe₃O₂
Nanothermite Sintered
CO₂ Sensor



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



Stress Monitoring of Astronaut Crew



- The job of an astronaut is stressful
- Stress can have negative affects on human performance





NASA MSFC Materials & Process Development Development of Printed Sensors

3D-Printed Cortisol Biosensor

Cortisol Detection:

Working Electrode Surface:

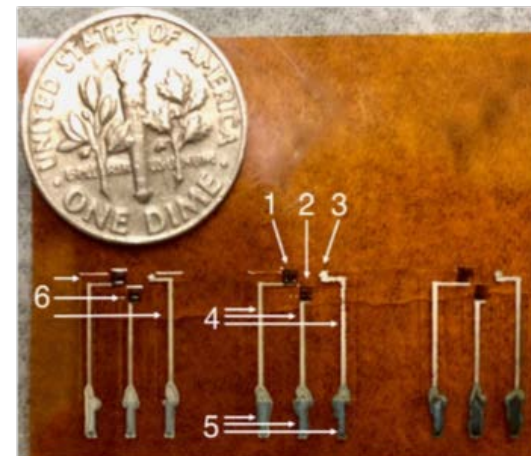
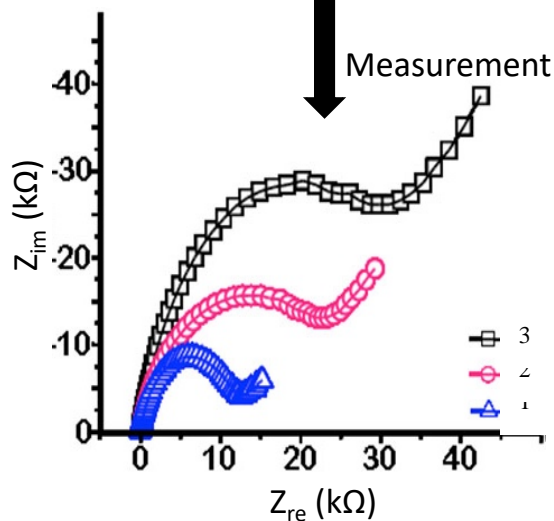
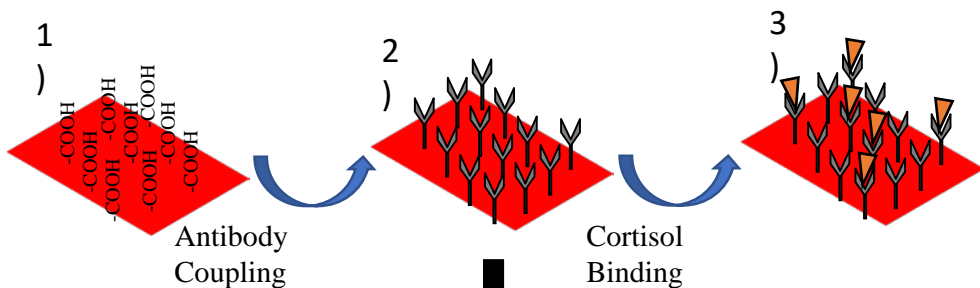
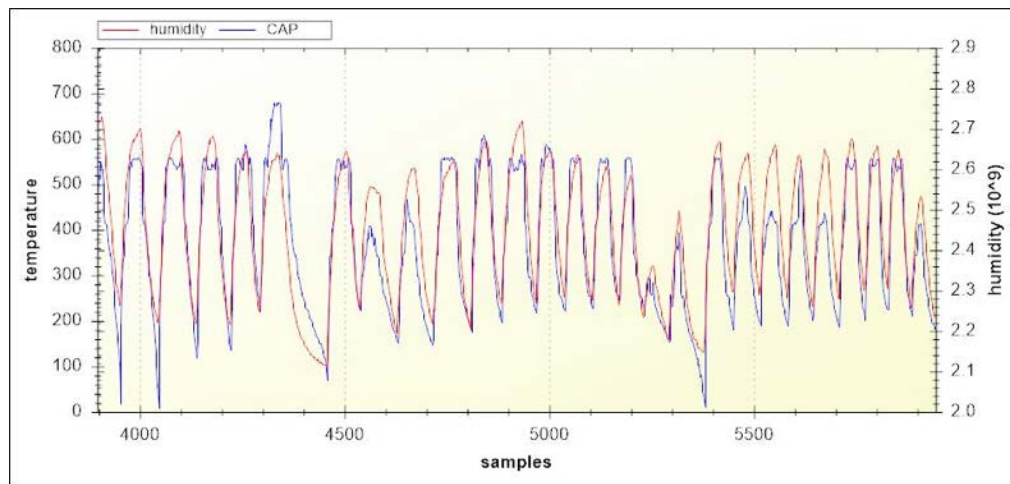
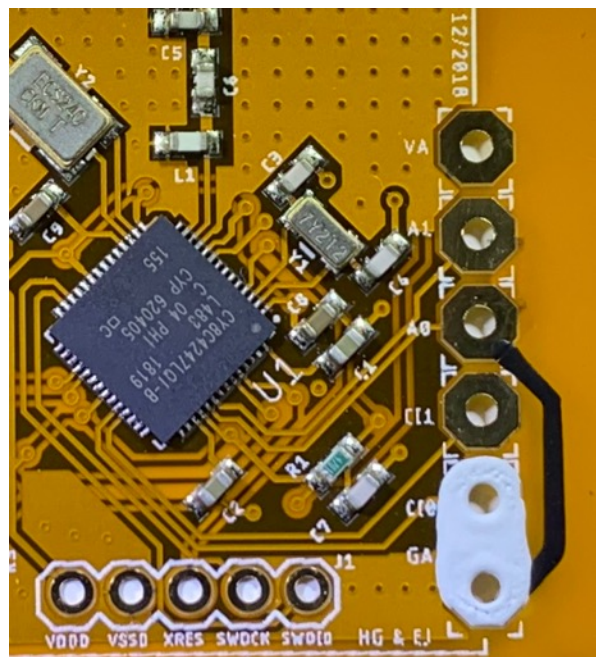


Figure 1. Printed electrochemical biosensor in polyimide substrate. 1) Counter electrode; 2) Working electrode; 3) reference electrode; 4) SU-8 layer; 5) Silver connection lead; 6) Connection pads.

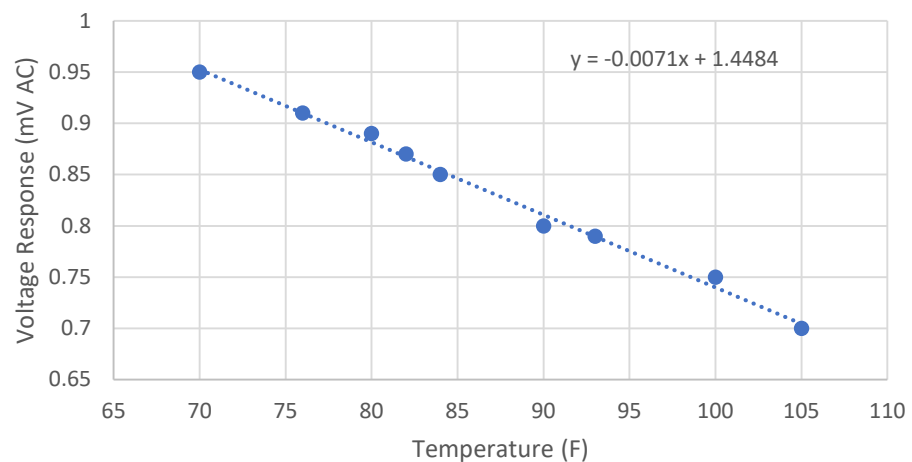


NASA MSFC Materials & Process Development Development of Printed Sensors

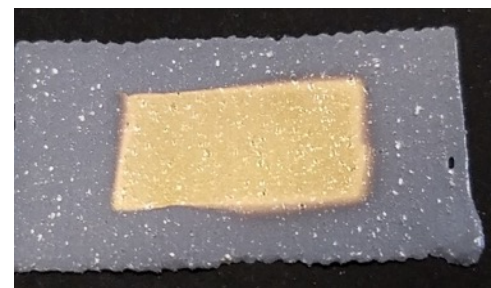


Humidity/Respiration Sensor

Sensor 1 Response to Temperature



Composite Temperature & Pressure Sensor





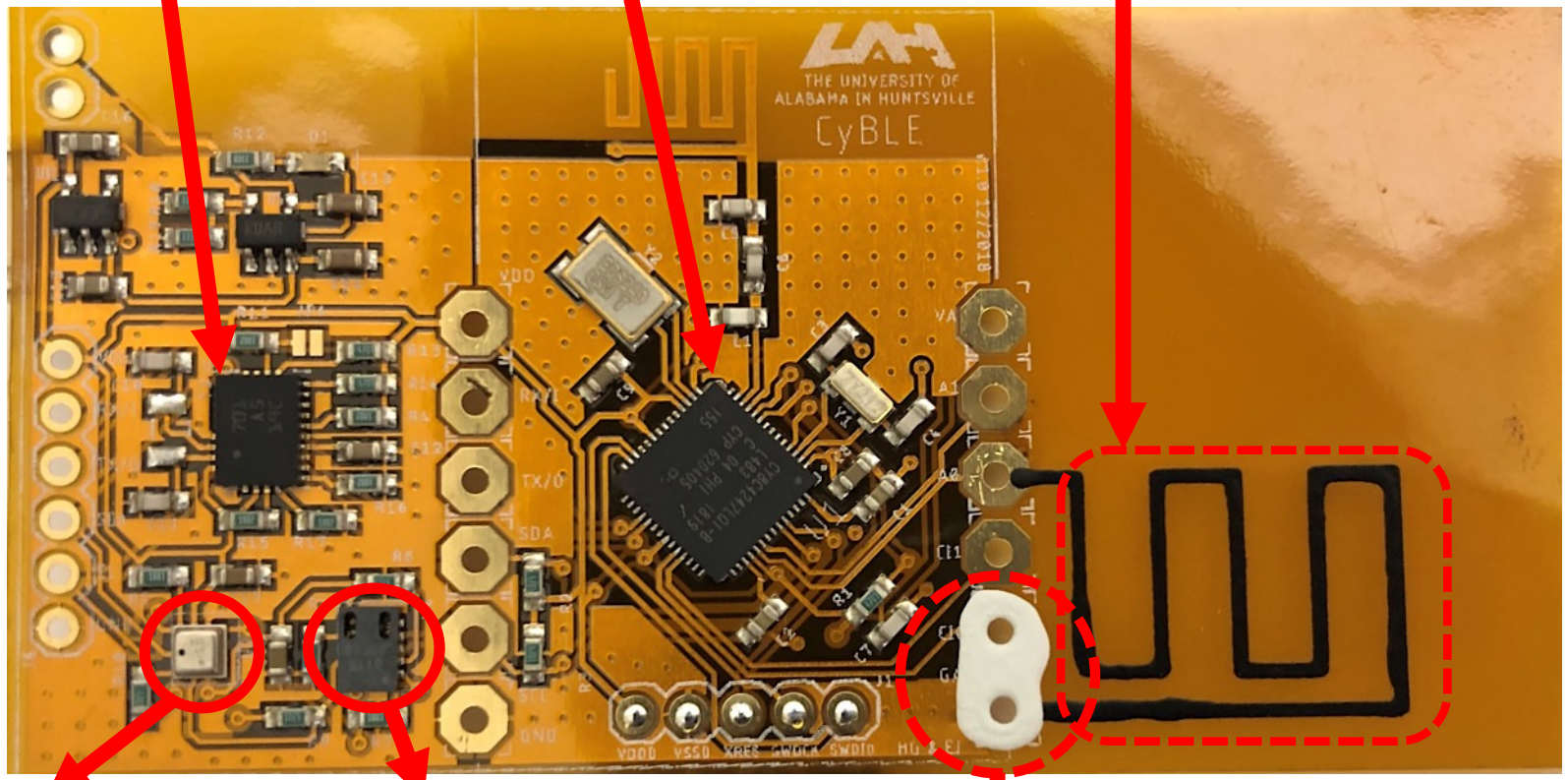
Flexible Wireless Sensor Board Demo



**9 DOF IMU sensor
(acc, gyro, magnetometer)**

**Low power
microcontroller & BLE**

**Printed
Temperature sensor**



**Bosch Temperature,
Humidity and Pressure sensor**

Gas sensor (CO2, TVOC)

Printed Humidity sensor

THE UNIVERSITY OF ALABAMA IN HUNTSVILLE
CyBLE

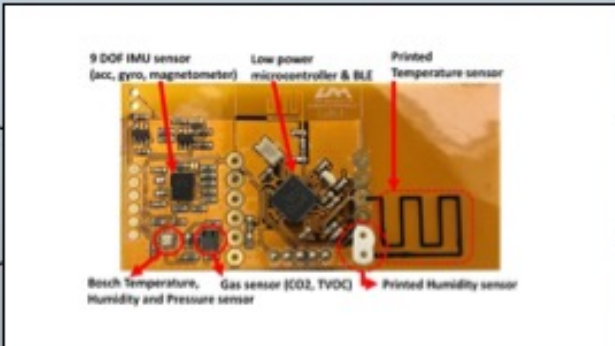


NASA MSFC Materials & Process Development Next-Generation Flexible Sensor Platforms

Printable gas & cortisol sensor development
NASA AMES

Development of integration & assembly technologies
NextFlex

NextFlex Integration *BETA* unit



Next-Generation AstroSense Wearable

Printable gas & humidity sensors development
NASA MSFC

Collaboration & interface
NASA JSC



NASA MSFC Materials & Process Development

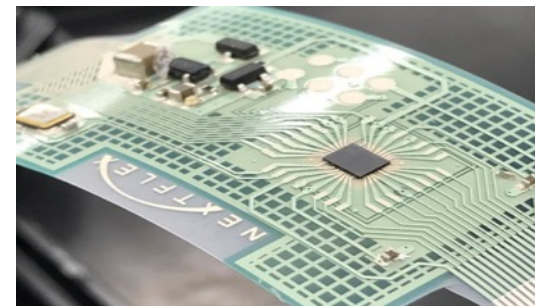
NextFlex Background



AstroSense Project



- Development of next-generation wearable sensor device for Crew Health Monitoring.
- “Peel & stick” wearable with an array of environmental and biosensors.
 - Humidity, temperature, CO2
 - First printed biosensor is cortisol
- New peel & reattach interconnection technology for replaceable cortisol sensors.
- Use of ultra-low power RFID wireless communications
 - Infrastructure already in place on ISS
 - Greater than 10 years battery life with CR2032 coin cell





MSFC Multi Material Fabrication Roadmap



Technology Development & Flight Support

Exploration & Habitat Support

Nanopowder development lab

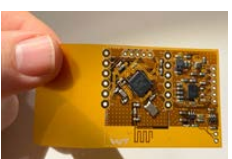


3D MMF printing and materials development lab



Materials synthesis & testing lab

Thin film print & 3D robotic MMF printing



FabLab Support (Metals, Electronics)

AstroSense Crew Health Sensor Device



Functional polymers

Battery replacement technologies

Exploration & Habitat Support

Lunar Gateway



Moon & Mars Habitats



2014 - 2017

2018-2019

2020-2024

2025 - 2035+

- Development of energy storage technologies:
 - Ultracapacitor
 - SPS Supercapacitor
- Development of printed sensor technologies:
 - Composite sensors
 - Dielectric humidity
 - Multi-gas sensors
- Development of Printed electronics technologies:
 - Electronic/functional inks
 - Thin & thick film deposition technologies
 - nScript multi-material 3D printing

- Development of energy & power technologies:
 - Printed supercapacitors
 - Energy harvesting
 - Thermoelectrics
- Development of flexible sensor platforms:
 - Next-generation environment sensors
 - Biosensor development
 - Outside partnerships for next-gen wearable devices
- 3D Printing of metals:
 - New powder micromilling processes
 - Laser sintering processes for ISS
 - High intensity directed energy sintering development

- Commercialization and space application of energy & power technologies:
 - Ultracapacitor
 - SPS Supercapacitor
 - Power generation & harvesting
- Development of advanced sensor technologies:
 - Smart swarm self-powered sensors for habitats
 - Next-gen printed biosensors
- Printed electronics technologies:
 - Multi-material printing for habitats
 - Utilization of regolith for electronics

Lunar Gateway Development

- Next-generation materials for sensors, energy storage & power generation.
- Materials & sensor support for next-generation EVA suits for exploration
- Structural Health Monitoring sensor materials & applications

Lunar Habitat

- Materials & processes for Lunar FabLab
- New solid-state energy storage for extended lunar use; energy harvesting technologies
- New thermoelectric materials for lunar power
- In situ materials utilization

Mars Habitat

- Materials & processes for Mars FabLab
- New solid-state energy storage for extended Mars & other exploration habitats use; energy harvesting technologies
- "Smart Swarm" self-powered sensors for environmental monitoring
- In situ materials utilization