Flexible Sensor Development for Astronaut Crew Health Monitoring

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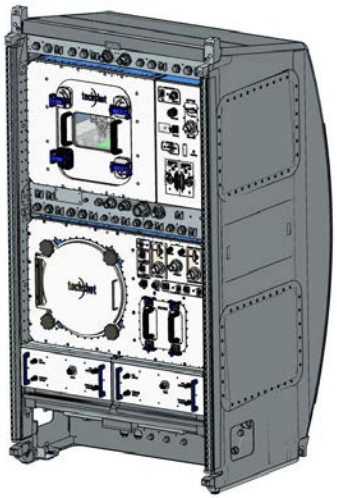
NASA MSFC Materials & Process Development
Background on In Space Manufacturing

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

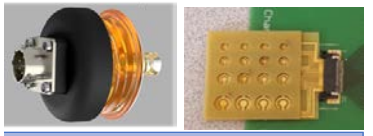
- ***In-Space Manufacturing Technology & Material Development: Work with industry and academia to develop on-demand manufacturing and repair technologies for in-space applications.***
  - ***Development of Crew Health Wearable Sensors***
  - ***Energy & Power Development***
- ***In-Space Recycling & 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)



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)

ISS Refabricator Demo with Tethers Unlimited, Inc.

NextSTEP

HAB

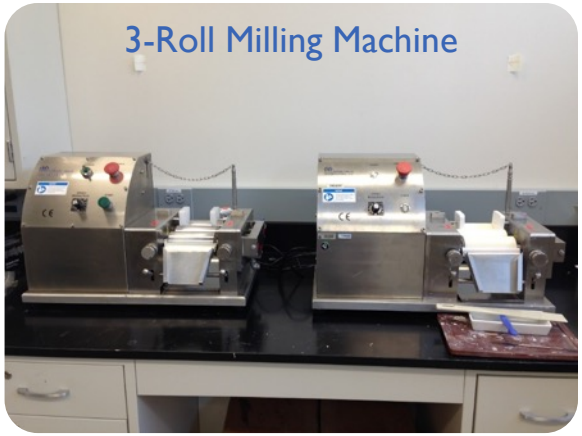
FUTURE ENGINEERS

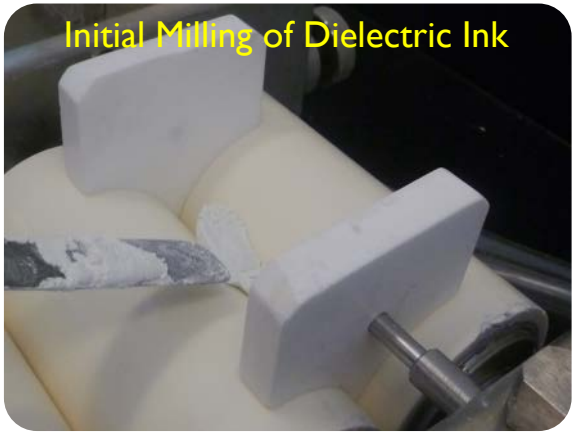
***Collaborative** Leveraging with Industry and Academia*

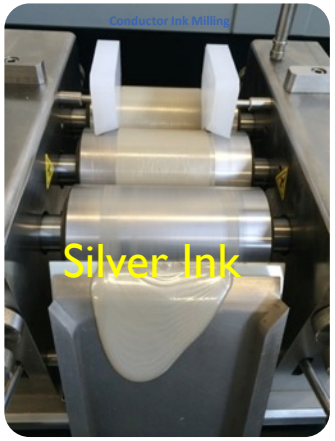
NASA MSFC Materials & Process Development Laboratory Capabilities

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

Material processing

3D Multi-Material Printers

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.
  - 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.

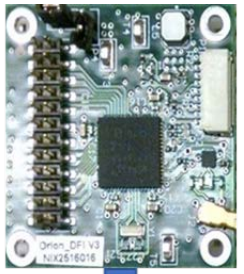
Voltera electronics printer

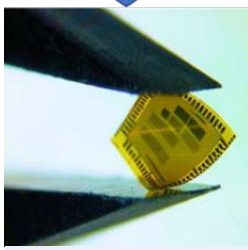
Voltera Electronics Printer

- 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

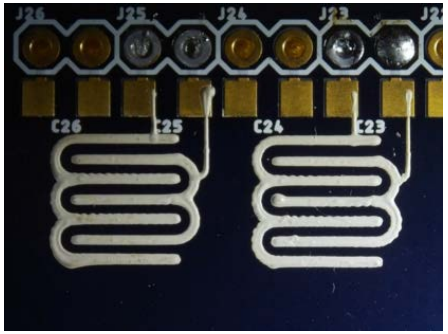




Flexible Electronics Sensors

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.)

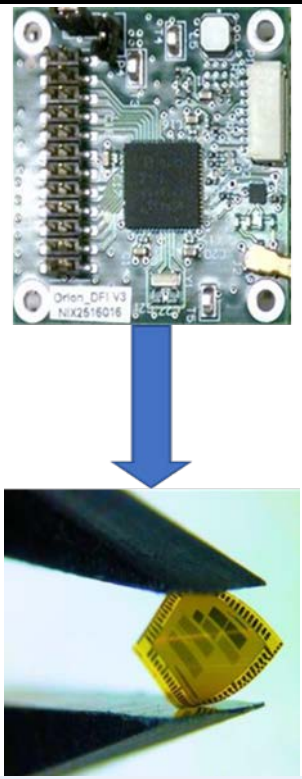


NASA MSFC Materials & Process Development
Flexible Sensing Technology

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

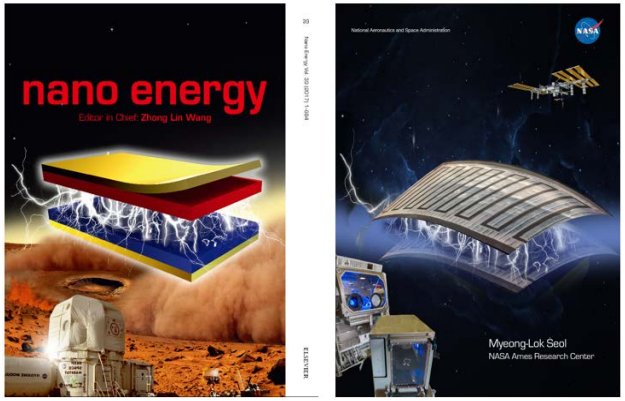
Energy & Power

ISM Multi Material Fabrication Key Areas:

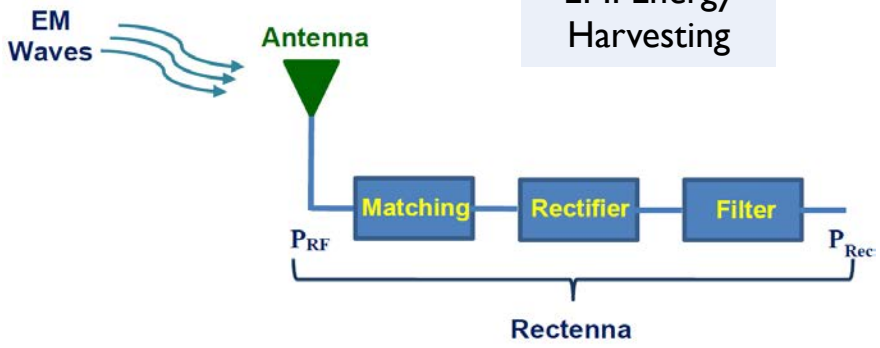
Power Generation Projects:

- Thermoelectric development – Research on doped ZnO and other materials with SPS sintered processing
- Thermoelectric development – research on SPS sintered InO_2
- Triboelectric generator development
- Electromagnetic radiation harvesting - "rectenna" printed antenna array.

TENG



EMI Energy Harvesting



NASA MSFC Materials & Process Development
Flexible Sensor Development

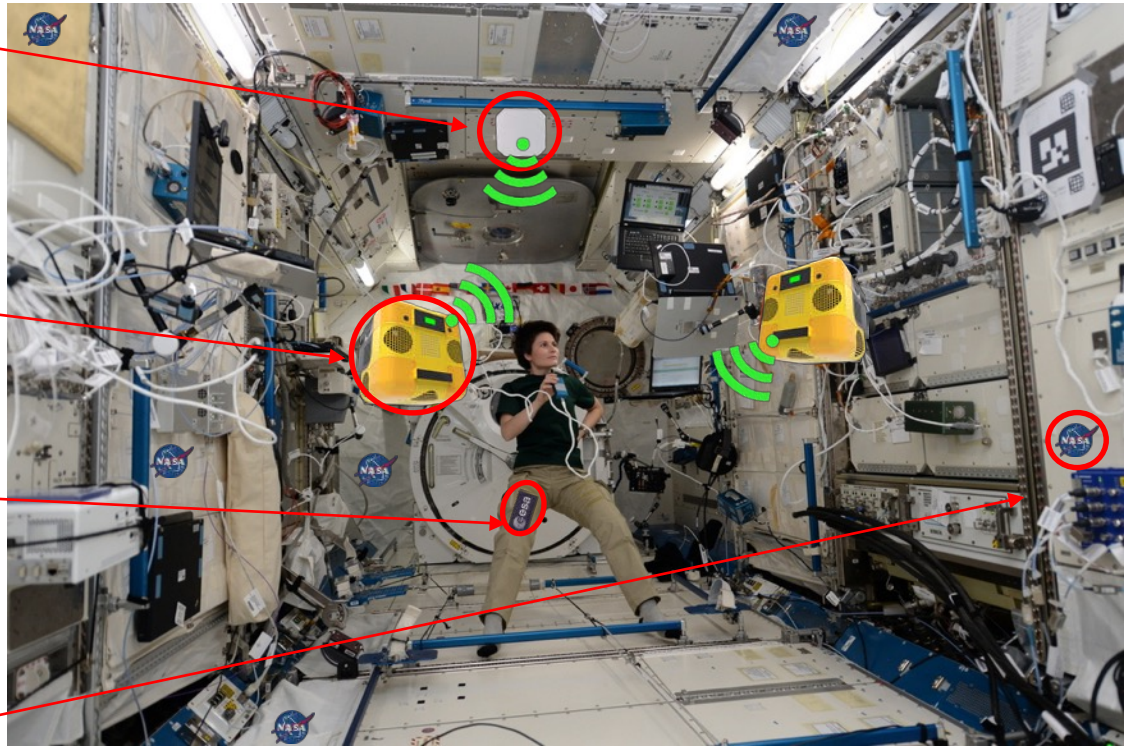
Wearable Wireless Sensors Operational Concept

fixed interrogator

mobile interrogator

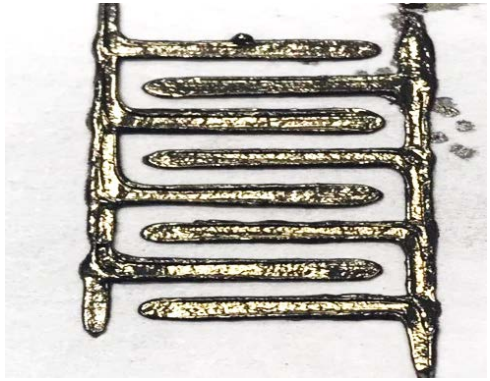
ultra-long battery life **wearable** sensor "patch"

wall-mounted ("peel-and-stick") sensor "patch"

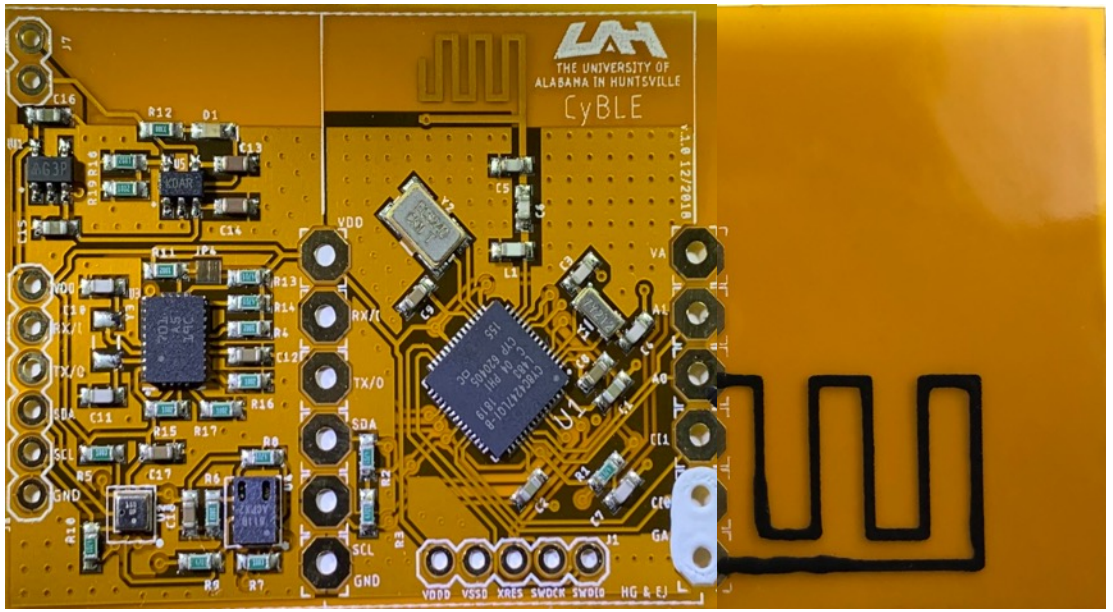


NASA MSFC Materials & Process Development
Next-Generation Flexible Sensor Platforms

First Generation Personal CO_2 Monitor



3D-Printed Al-Fe_3O_2 Nanothermite Sintered CO_2 Sensor



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

Stress Monitoring of Astronaut Crew

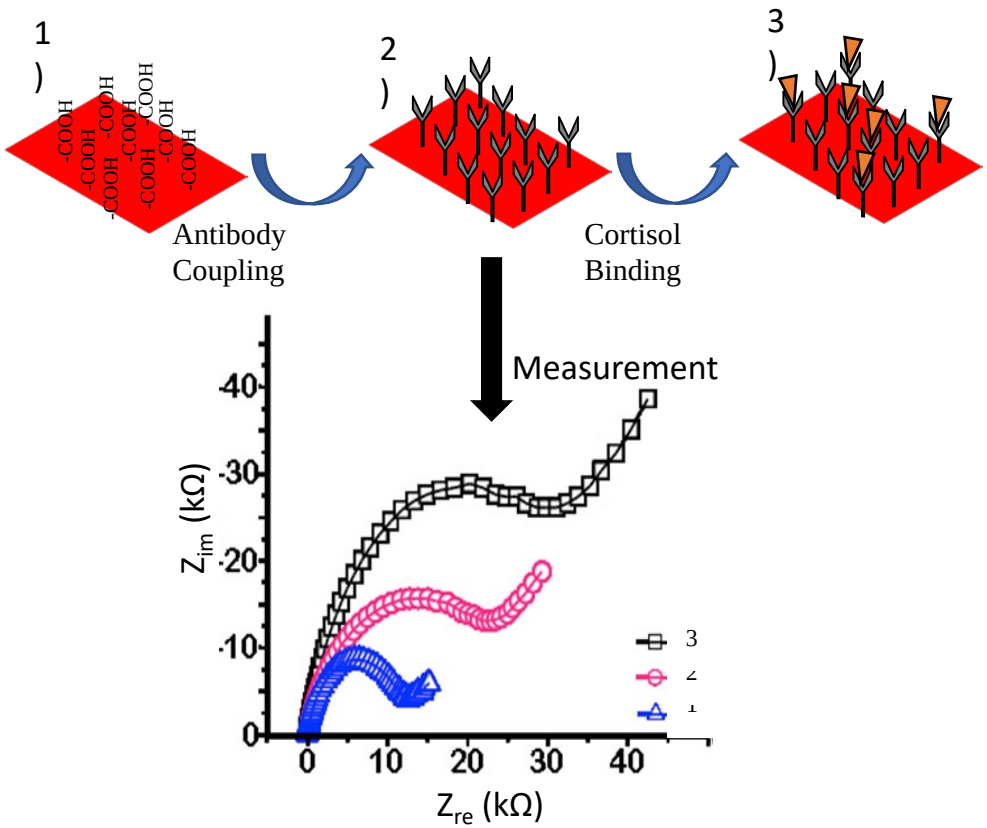
- The job of an astronaut is stressful
- Stress can have negative affects on human performance

NASA MSFC Materials & Process Development
Development of Printed Sensors

3D-Printed Cortisol Biosensor

Cortisol Detection:

Working Electrode Surface:



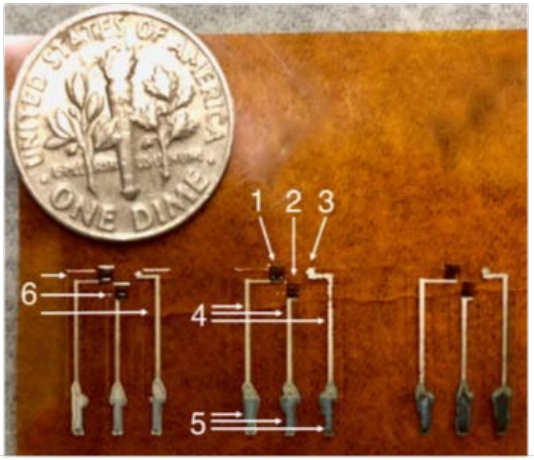
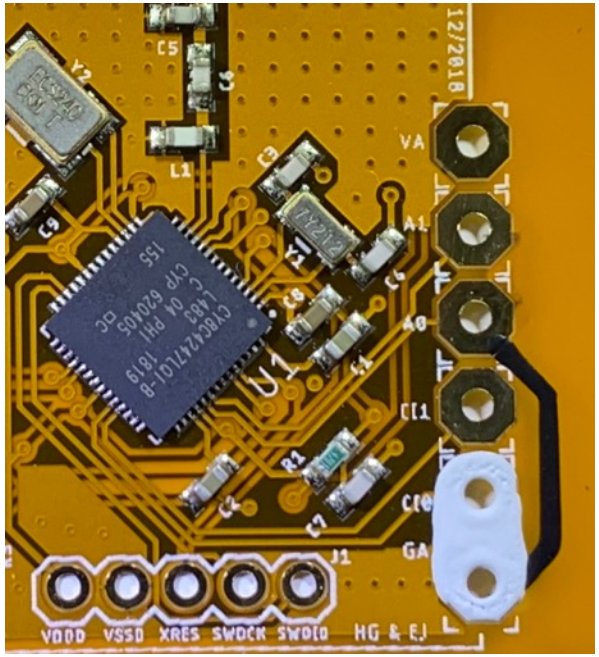
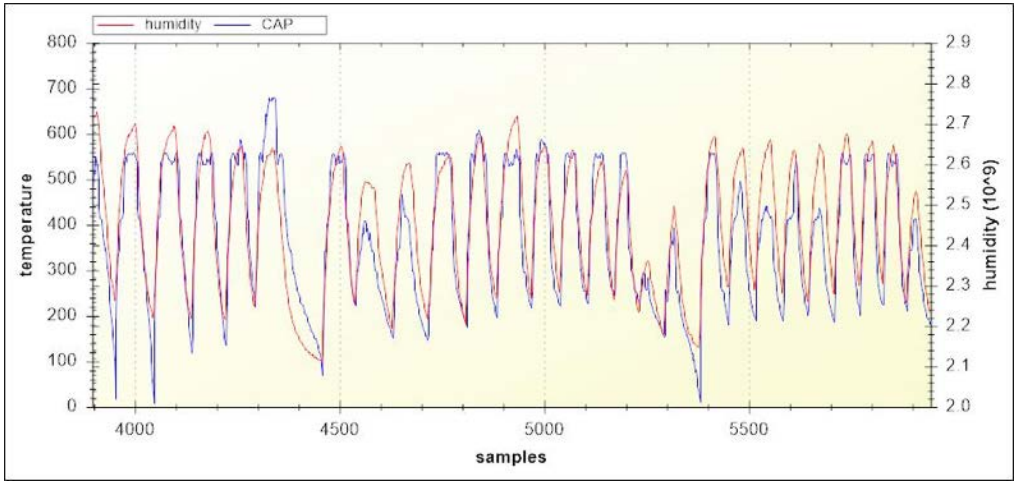


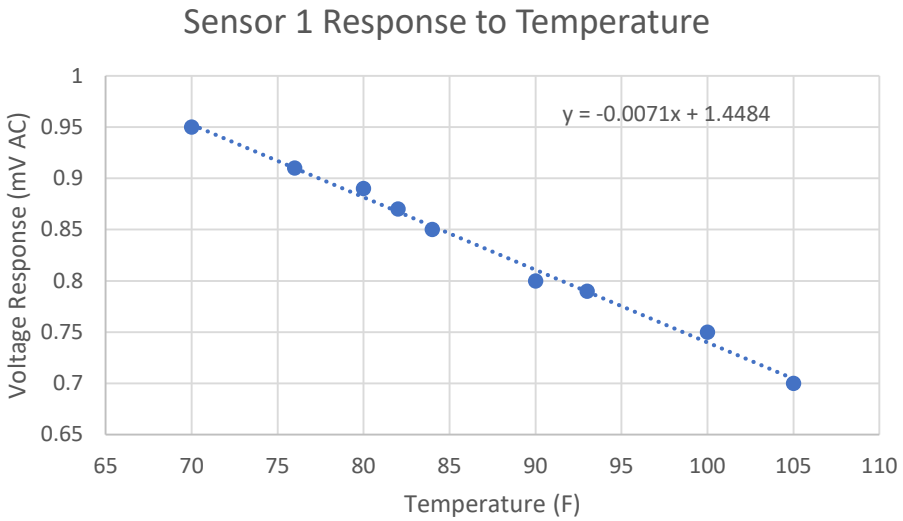
Figure 1. Printed electrochemical biosensor in polyimide substrate. 1) Counter electrode; 2) Working electrode; 3) reference electrode; 4) SU-8 layer; 5) Silver connection lead; 6) Connection pads.

NASA MSFC Materials & Process Development
Development of Printed Sensors

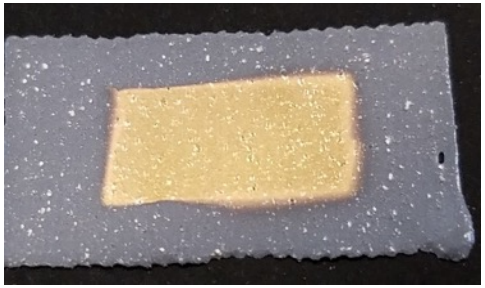




Humidity/Respiration Sensor



Composite Temperature & Pressure Sensor

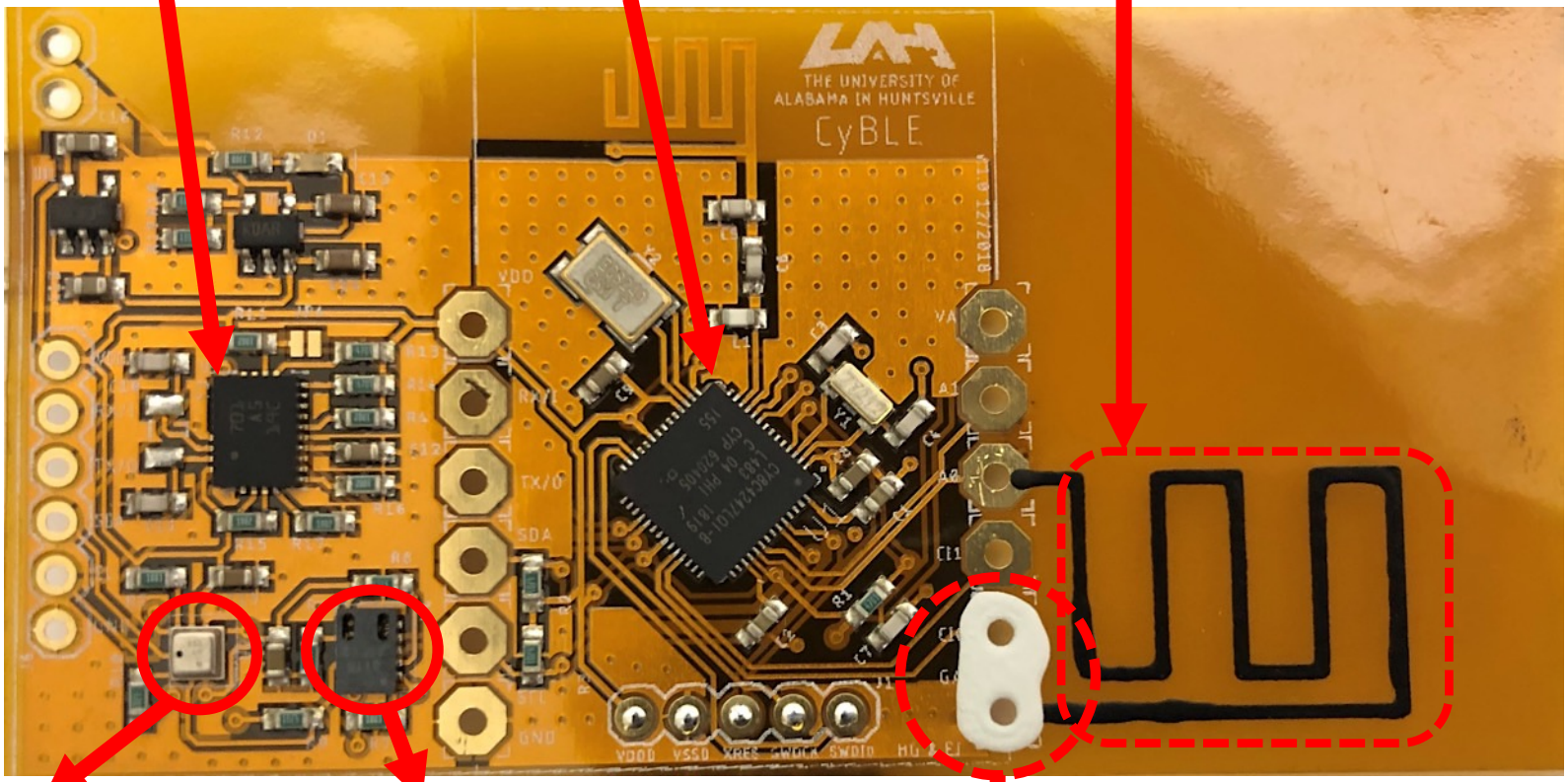


Flexible Wireless Sensor Board Demo

9 DOF IMU sensor
(acc, gyro, magnetometer)

Low power
microcontroller & BLE

Printed
Temperature sensor



Bosch Temperature,
Humidity and Pressure sensor

Gas sensor (CO2, TVOC)

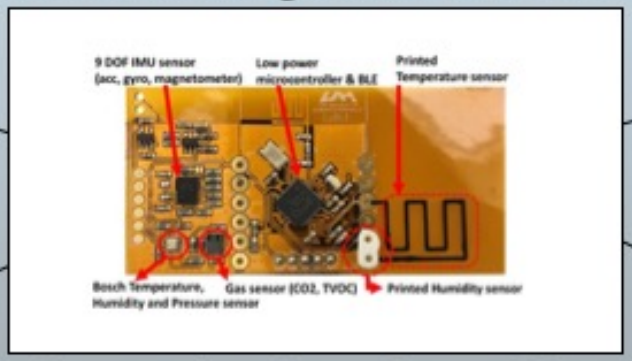
Printed Humidity sensor

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

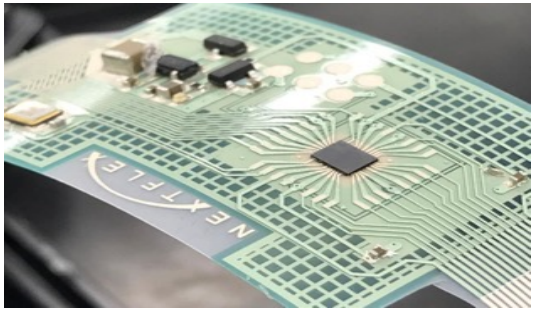
Printable gas & humidity sensors development
NASA MSFC

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

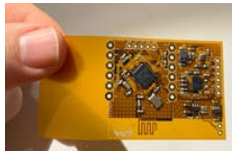
Technology Development & Flight Support

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

- 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**
  - **nScrypt multi-material 3D printing**

2018-2019

- 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**

2020-2024

- 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**

2025 - 2035+

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**

ISM MMF in development of high performance materials & processes for ISS, Habitats, & Exploration.