



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.

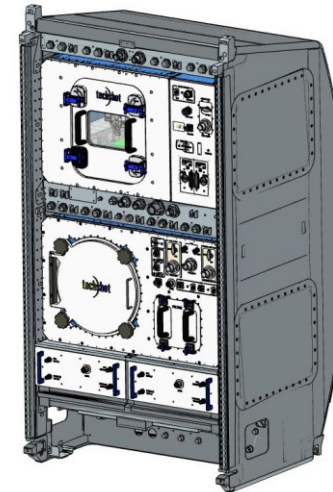
❖ **In-Space Manufacturing Digital Design & Verification Database (i.e. WHAT we need to make):** ISM is working with Exploration System Designers to develop the ISM database of parts/systems to be manufactured on spaceflight missions.



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



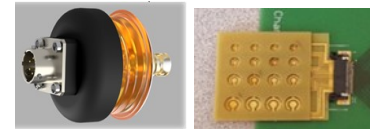
ISS Refabricator Demo with Tethers Unlimited, Inc.



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

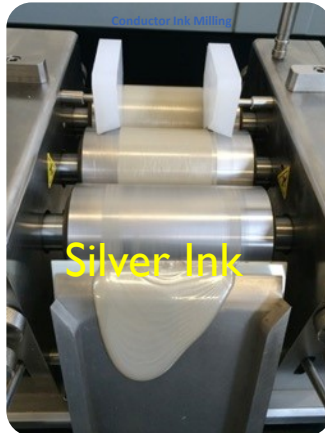


NASA MSFC Materials & Process Development Laboratory Capabilities



Nanoinks Development & Processing

Ink Formulation



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

Material processing

3D Multi-Material Printers



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.

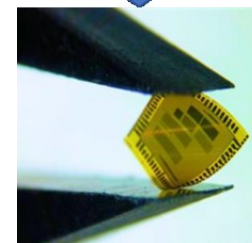


NASA MSFC Materials & Process Development Flexible Sensor Development

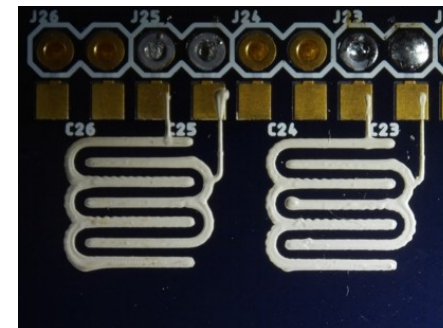
Multi Material Fabrication and Materials Development

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





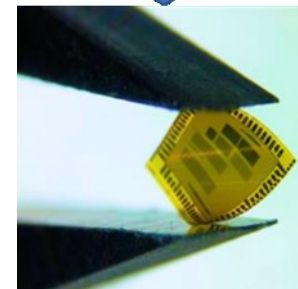
NASA MSFC Materials & Process Development Flexible Sensing Technology



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

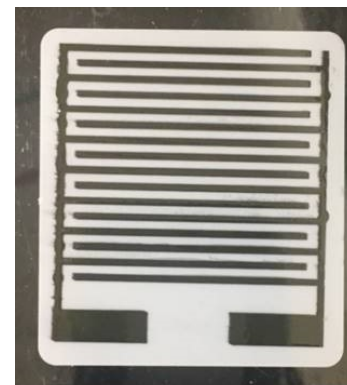


Energy & Power

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



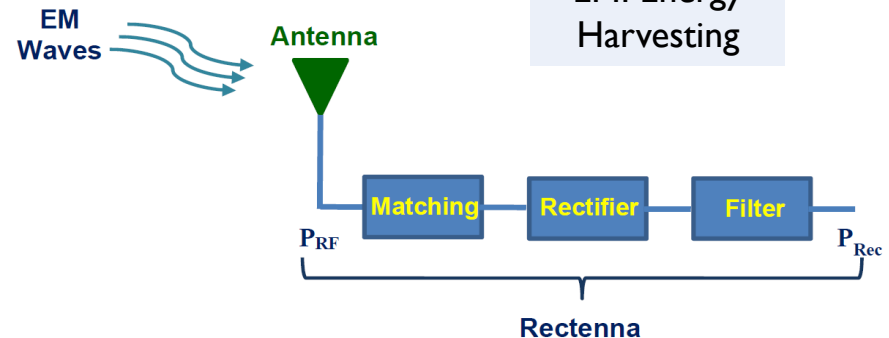
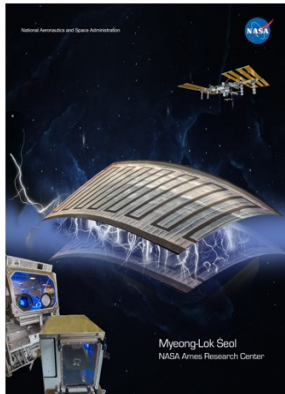
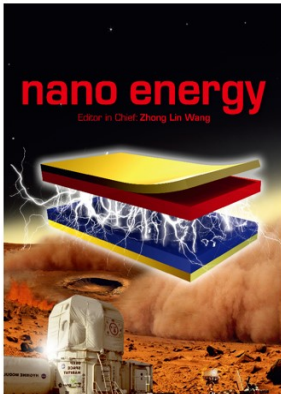
NASA MSFC Materials & Process Development

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

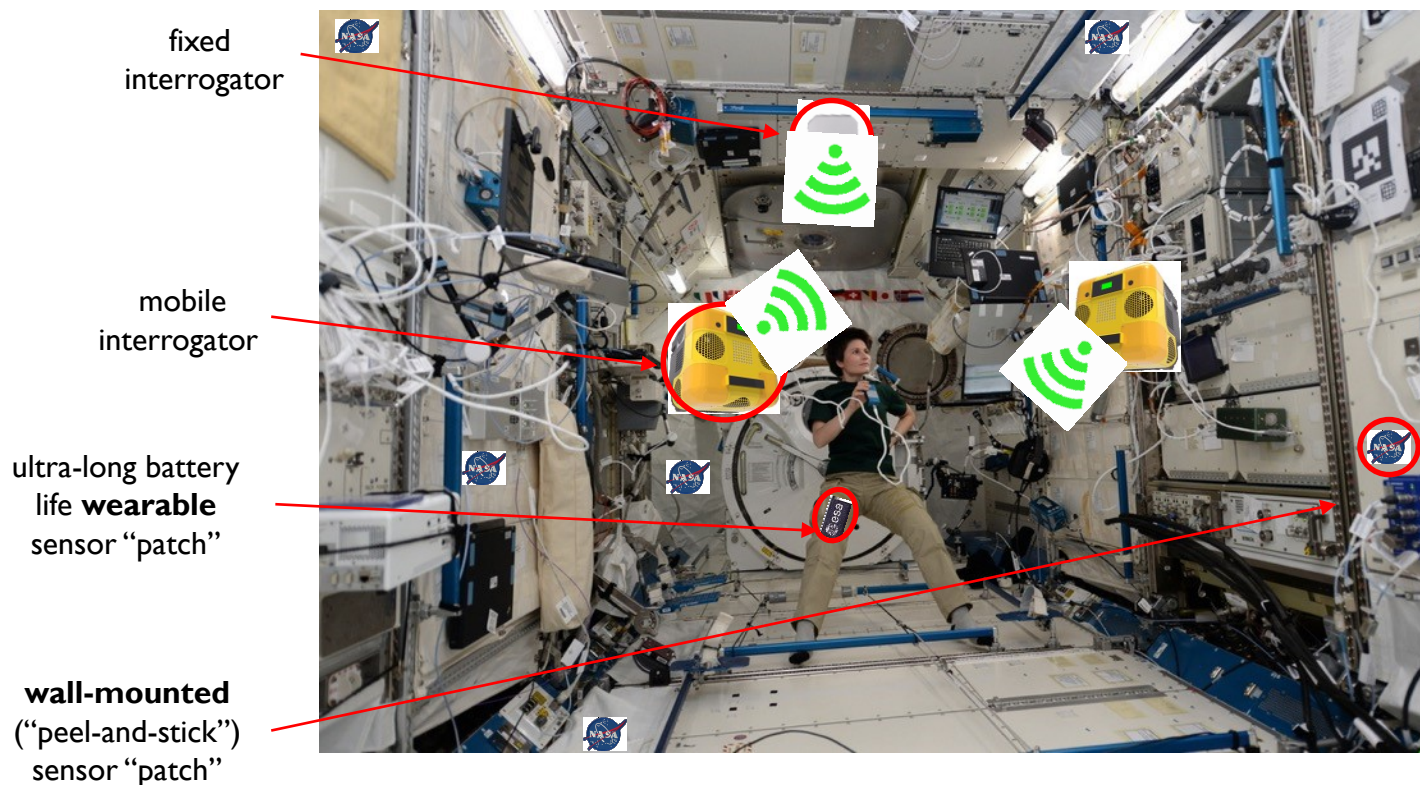




NASA MSFC Materials & Process Development Flexible Sensor Development



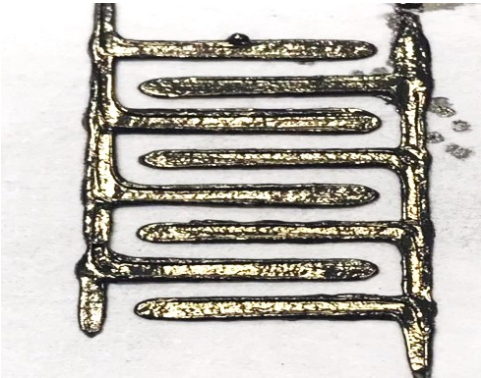
Wearable Wireless Sensors Operational Concept



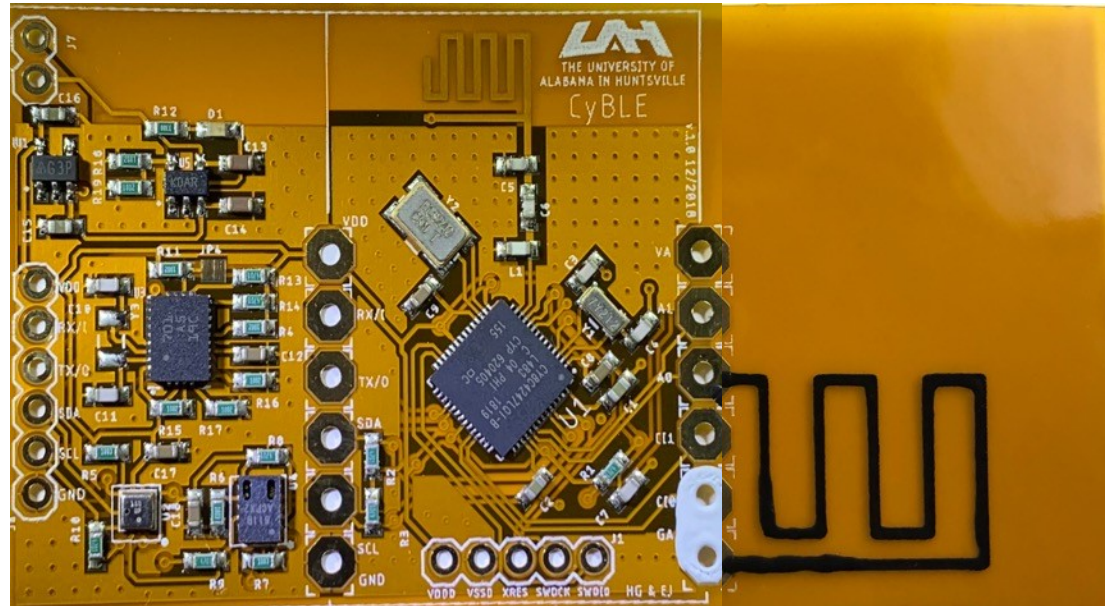


NASA MSFC Materials & Process Development Next-Generation Flexible Sensor Platforms

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:

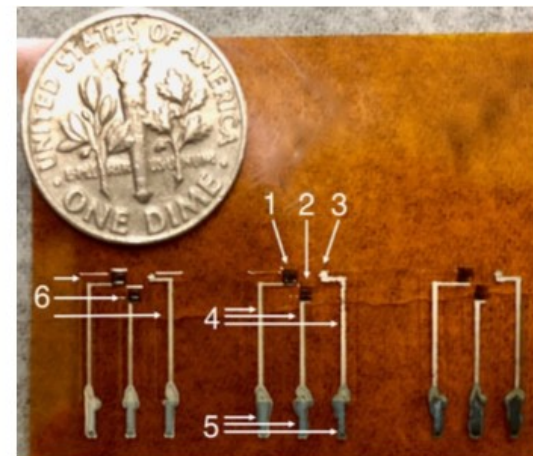
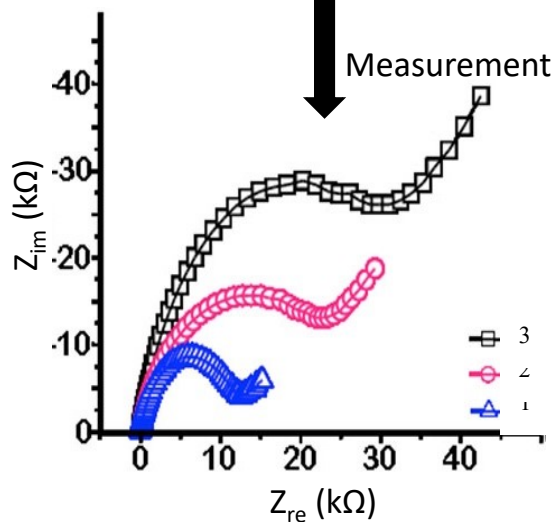
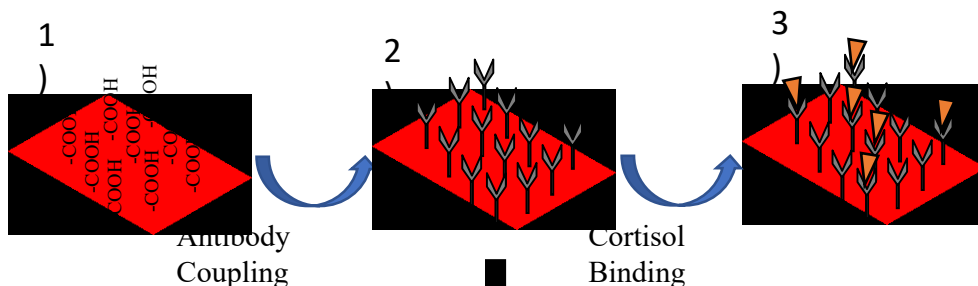
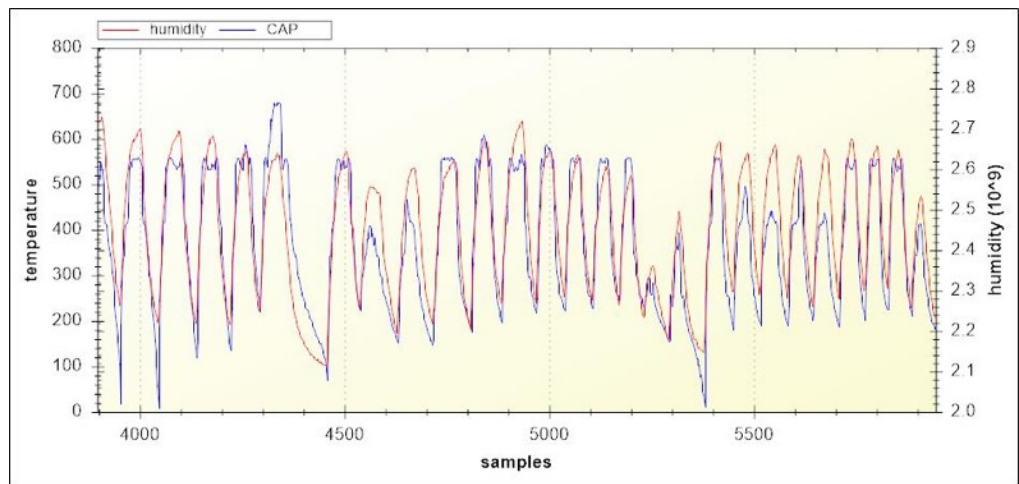
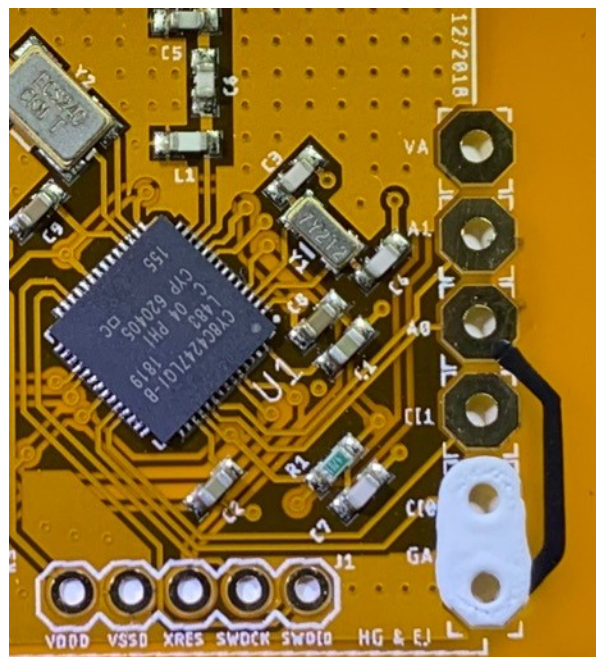


Figure 1. Printed electrochemical biosensor in polyimide substrate. 1) Counter electrode; 2) Working electrode; 3) reference electrode; 4) SU-8 layer; 5) Silver connection lead; 6) Connection pads.



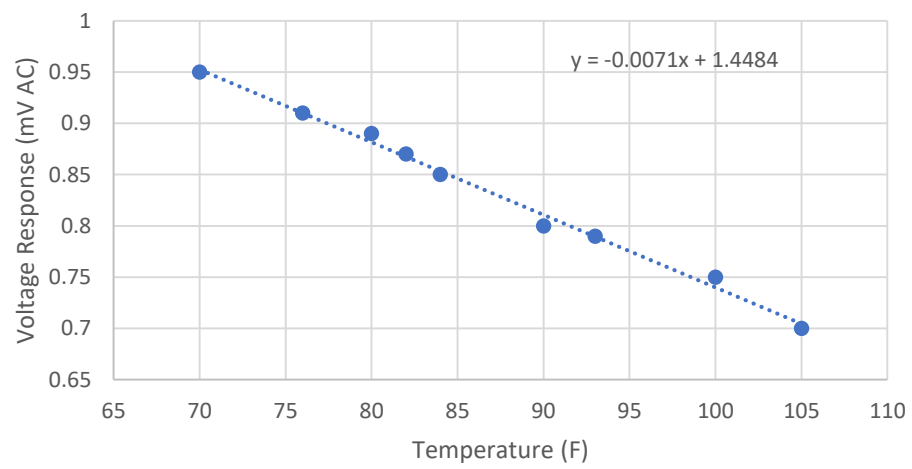
NASA MSFC Materials & Process Development

Development of Printed Sensors

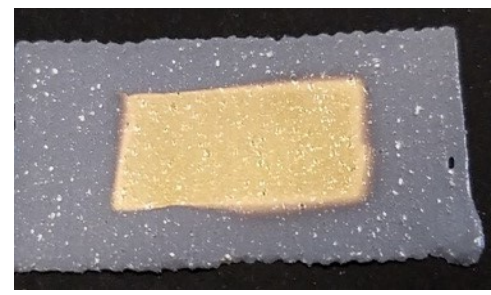


Humidity/Respiration Sensor

Sensor 1 Response to Temperature



Composite Temperature & Pressure Sensor



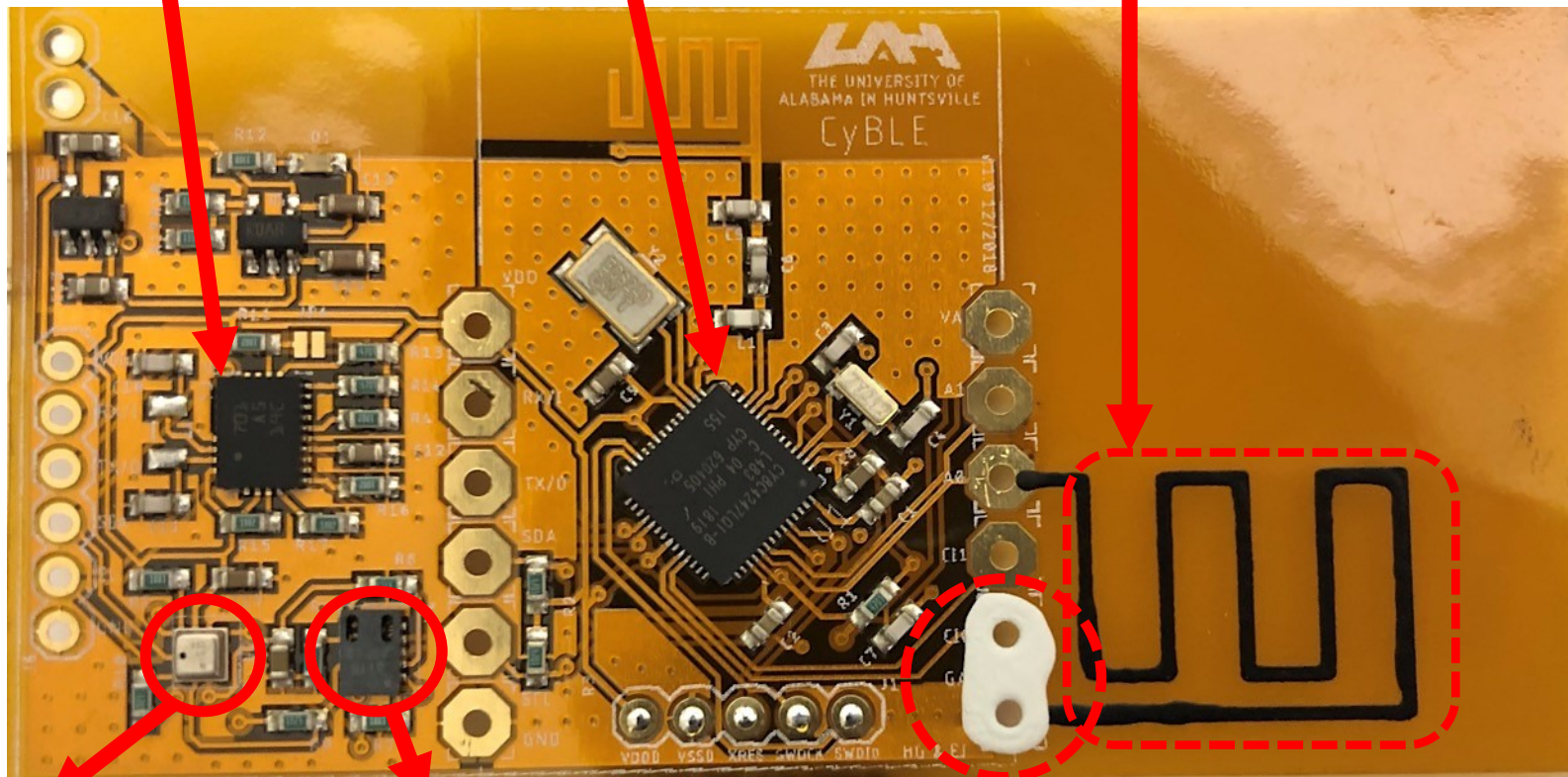


Flexible Wireless Sensor Board Demo

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

**Low power
microcontroller & BLE**

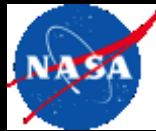
**Printed
Temperature sensor**



**Bosch Temperature,
Humidity and Pressure sensor**

Gas sensor (CO₂, TVOC)

Printed Humidity sensor



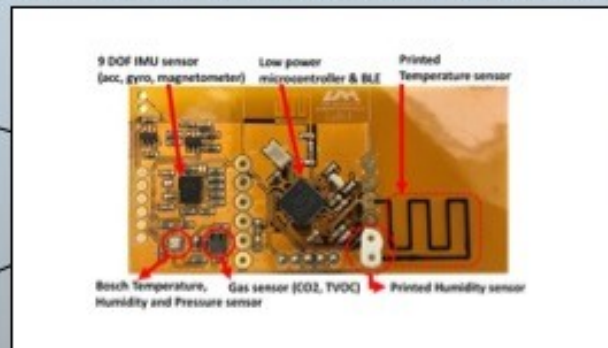
NASA MSFC Materials & Process Development

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



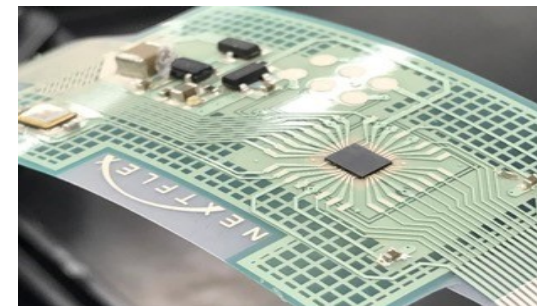
NASA MSFC Materials & Process Development NextFlex Background



AstroSense Project



- Development of next-generation wearable sensor device for Crew Health Monitoring.
- Phase I effort:
 - Development of reliable interconnect for physiological sensors.
 - Electrical and mechanical design of the flexible hybrid electronics sensor board.
 - Modeling, testing, and evaluation of communications (Bluetooth Low Energy – BLE) and microprocessor chipsets to determine the optimum match for the electrical design in terms of performance vs. power requirement.
 - Development of process for direct die attach of low-power BLE chipset to flexible polyimide (PI) board.





MSFC Multi Material Fabrication Roadmap



Technology Development & Flight Support

Nanopowder development lab

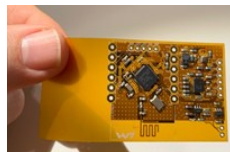


3D MMF printing and materials development lab



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

2014 - 2017

2018-2019

2020-2024

Exploration & Habitat Support

Lunar Gateway



Moon & Mars Habitats



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**