Flexible Sensor Development for Astronaut Crew Health Monitoring

Curtis Hill
NASA
MSFC/ESSCA
October 2019
**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.
Nanoinks Development & Processing

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 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.
3D Multi-Material Printers

**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**

- 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.
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.)
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.
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.
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.
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
Flexible Sensor Development
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
3D-Printed Cortisol Biosensor

Cortisol Detection:

Working Electrode Surface:

Antibody Coupling

Cortisol Binding

Measurement

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.
Humidity/Respiration Sensor

Sensor 1 Response to Temperature

\[ y = -0.0071x + 1.4484 \]

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
AstroSense Project

- Development of next-generation wearable sensor device for Crew Health Monitoring.

- Phase 1 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.
### NASA MSFC Multi Material Fabrication

**Technology Development & Flight Support**

- **Nanopowder development lab**
- **Materials synthesis & testing lab**
- **FabLab Support (Metals, Electronics)**
- **Thin film print & 3D robotic MMF printing**
- **Functional polymers**
- **Battery replacement technologies**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Development of energy storage technologies:</td>
<td>• Ultracapacitor</td>
<td>• Printed supercapacitors</td>
<td>• Next-generation materials for sensors, energy storage &amp; power generation.</td>
</tr>
<tr>
<td>• SPS Supercapacitor</td>
<td>• Energy harvesting</td>
<td>• Materials &amp; processes for Lunar FabLab</td>
<td></td>
</tr>
<tr>
<td>Development of printed sensor technologies:</td>
<td>• Thermoelectrics</td>
<td>• Power generation &amp; harvesting</td>
<td>• New solid-state energy storage for extended lunar use; energy harvesting technologies.</td>
</tr>
<tr>
<td>• Composite sensors</td>
<td>• Development of flexible sensor platforms:</td>
<td>• Smart swarm self-powered sensors for habitats</td>
<td>• New thermoelectric materials for lunar power</td>
</tr>
<tr>
<td>• Dielectric humidity</td>
<td>• Next-generation environment sensors</td>
<td>• Next-gen printed biosensors</td>
<td>In situ materials utilization</td>
</tr>
<tr>
<td>• Multi-gas sensors</td>
<td>• Biosensor development</td>
<td>• Structural Health Monitoring sensor materials &amp; applications</td>
<td>“Smart Swarm” self-powered sensors for environmental monitoring</td>
</tr>
<tr>
<td>Development of Printed electronics technologies:</td>
<td>• Outside partnerships for next-gen wearable devices</td>
<td>• Structural Health Monitoring sensor materials &amp; applications</td>
<td>In situ materials utilization</td>
</tr>
<tr>
<td>• Electronic/functional inks</td>
<td>• 3D Printing of metals:</td>
<td>• Commercialization and space application of energy &amp; power technologies:</td>
<td></td>
</tr>
<tr>
<td>• Thin &amp; thick film deposition technologies</td>
<td>• New powder micromilling processes</td>
<td>• Ultracapacitor</td>
<td>• Materials &amp; processes for Mars FabLab</td>
</tr>
<tr>
<td>• nScrypt multi-material 3D printing</td>
<td>• Laser sintering processes for ISS</td>
<td>• SPS Supercapacitor</td>
<td>• New solid-state energy storage for extended Mars &amp; other exploration habitats use; energy harvesting technologies</td>
</tr>
<tr>
<td></td>
<td>• High intensity directed energy sintering development</td>
<td>• Power generation &amp; harvesting</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Development of advanced sensor technologies:</td>
<td>• New “Smart Swarm” self-powered sensors for environmental monitoring</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Smart swarm self-powered sensors for habitats</td>
<td>In situ materials utilization</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Next-gen printed biosensors</td>
<td>• Structural Health Monitoring sensor materials &amp; applications</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Printed electronics technologies:</td>
<td>• Commercialization and space application of energy &amp; power technologies:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Multi-material printing for habitats</td>
<td>• Ultracapacitor</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Utilization of regolith for electronics</td>
<td>• SPS Supercapacitor</td>
</tr>
</tbody>
</table>

**Exploration & Habitat Support**

- **Lunar Gateway**
- **Moon & Mars Habitats**

<table>
<thead>
<tr>
<th>Lunar Gateway Development</th>
<th>Lunar Habitat</th>
<th>Mars Habitat</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Next-generation materials for sensors, energy storage &amp; power generation.</td>
<td>• Materials &amp; processes for Lunar FabLab</td>
<td>• Materials &amp; processes for Mars FabLab</td>
</tr>
<tr>
<td>• Materials &amp; sensor support for next-generation EVA suits for exploration</td>
<td>• New solid-state energy storage for extended lunar use; energy harvesting technologies</td>
<td>• New solid-state energy storage for extended Mars &amp; other exploration habitats use; energy harvesting technologies</td>
</tr>
<tr>
<td>• Structural Health Monitoring sensor materials &amp; applications</td>
<td>• New thermoelectric materials for lunar power</td>
<td>• “Smart Swarm” self-powered sensors for environmental monitoring</td>
</tr>
<tr>
<td></td>
<td>• In situ materials utilization</td>
<td>In situ materials utilization</td>
</tr>
</tbody>
</table>

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