Development of a Multi-Gas Microsensor Array for the Exploration Portable Life Support System

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Introduction to Makel Engineering Inc.

MEI Formed 1996
- HQ in Chico California

Multidisciplinary Team
- Chemical, Mechanical and Electrical Engineering
- Technicians and support staff

Facilities
- 16,000 ft^2
- Office, laboratories, manufacturing

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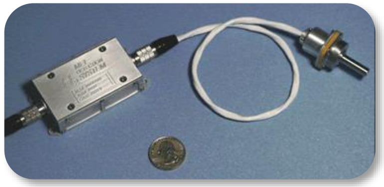

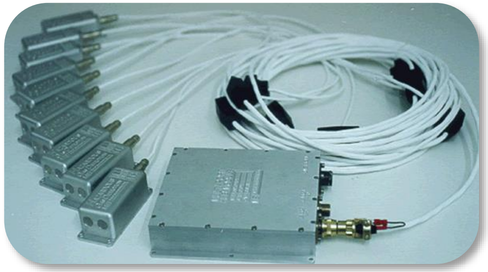

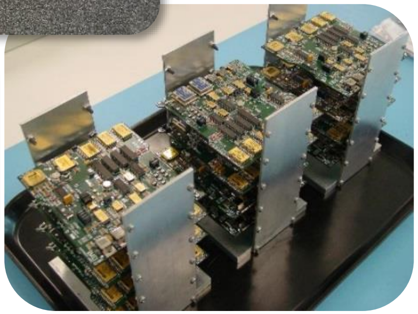

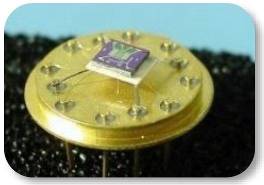

MEI Sensing Systems

- Aerospace
  - Launch Vehicles and ISS
  - Test Facilities
  - Planetary Exploration

- Defense
  - Aircraft Life Support Systems
  - Advanced Propulsion System Sensors
  - Warfighter Physiological Monitoring

- Industrial
  - Emissions Monitoring
  - Nuclear Systems Monitoring
  - Biomedical

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Overview

- Background and Motivation
  - Need for multi-gas measurement
- Sensor Operating Principles
  - Solid-state microsensors for O_2 and CO_2
- Sensor Assembly Design
  - Size and power compared to existing sensors
- Prototype Testing and Performance
  - Measurement accuracy and range
- Conclusions and Next Steps

Background and Motivation

Background and Motivation

- New spacesuits are being developed to support exploration objectives to the Moon and beyond

- Technology gaps have been identified during the development of these spacesuits

- There is a need to monitor multiple species in the breathing gas stream (O_2, CO_2, Humidity)

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Sensor Requirements

- Current PLSS design only includes nondispersive infrared (NDIR) sensors for CO_2
  - NDIR sensors outer mold is approximately 2.3 by 2.2 by 6.1 inches and power consumption is approximately 2 W
- Need to measure the major constituents of the breathing gas to provide general situational awareness
  - O_2 (20-100% ±1%)
  - CO_2 (0-30 torr ±0.3 torr)
  - H_2O (5-90% Relative Humidity ±1%)

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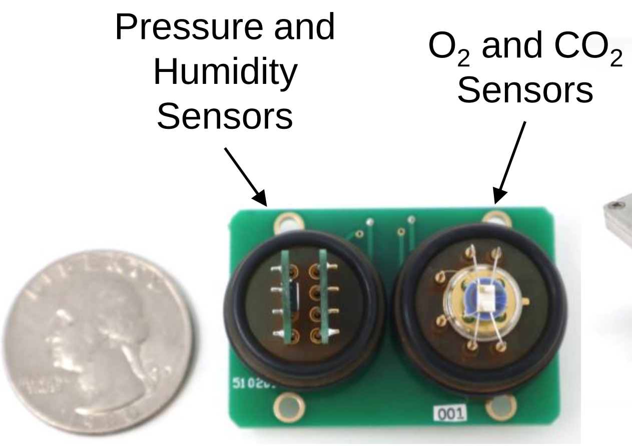
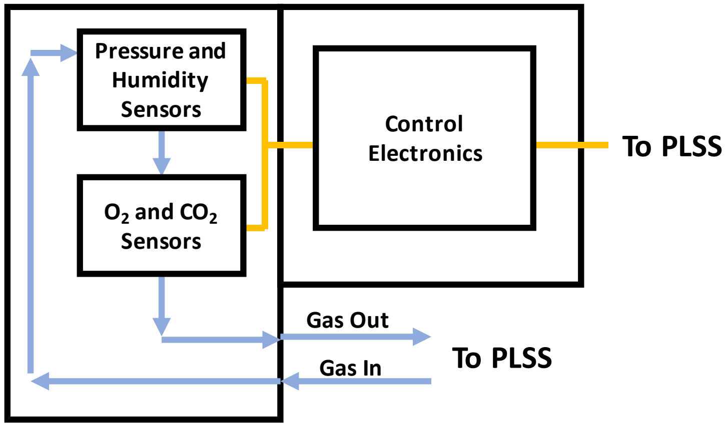
M-PALSS

- Multi-Parameter Astronaut Life Support Sensor
  - O_2, CO_2, Humidity, and Pressure
- Suitable for ground testing and compatible with existing NASA test equipment
- Does not meet all requirements for space flight





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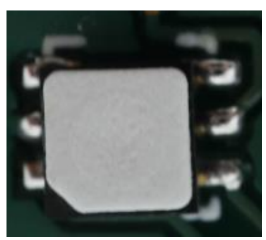
Sensor Operating Principles

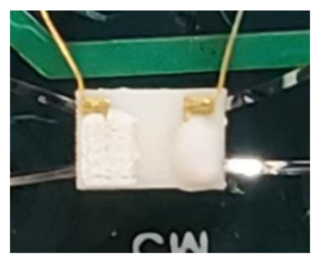
Solid-State Sensing

- Directly transduces a chemical signal to an electrical signal (resistance, current, or voltage)
- Small and low power
- Good match for PLSS situational awareness requirements

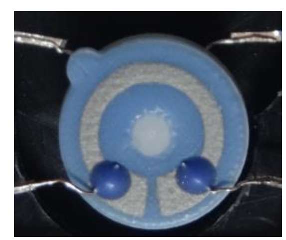
Pressure Sensor



Humidity Sensor



Carbon Dioxide Sensor



Oxygen Sensor

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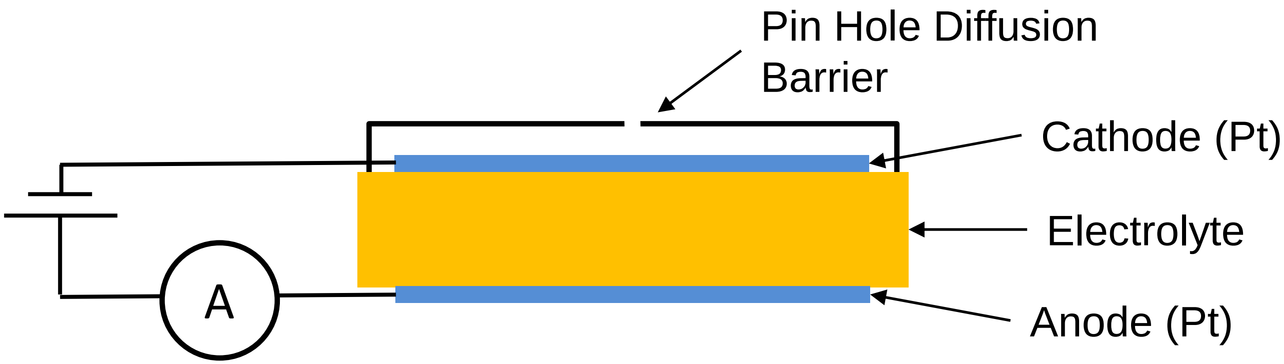
Amperometric Oxygen Sensor

- Oxygen sensor produces electrical current when a voltage bias is applied across the electrodes



$$O_2 + 4e^- \leftrightarrow 2O^{2-}$$

$$J_{O2} = -D_{O2}A\left(\frac{dC_{O2}}{dx}\right) + J\left(\frac{C_{O2}}{C}\right)$$

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Oxygen Sensor Calibration Derivation

$$J_{O2} = -D_{O2}A\left(\frac{dC_{O2}}{dx}\right) + J\left(\frac{C_{O2}}{C}\right)$$

$$I_{sensor} = 4FJ_{O2}$$

$$I_{sensor} = \frac{4FD_{O2}AC}{L}\ln\left(\frac{1-\frac{C_{O2}(L)}{C}}{1-\frac{C_{O2}(0)}{C}}\right)$$

$$\frac{C_{O2}(L)}{C} \ll 1$$

$$\boldsymbol{I_{sensor} = -k\ln\left(1-\frac{C_{O2}(0)}{C}\right)}$$

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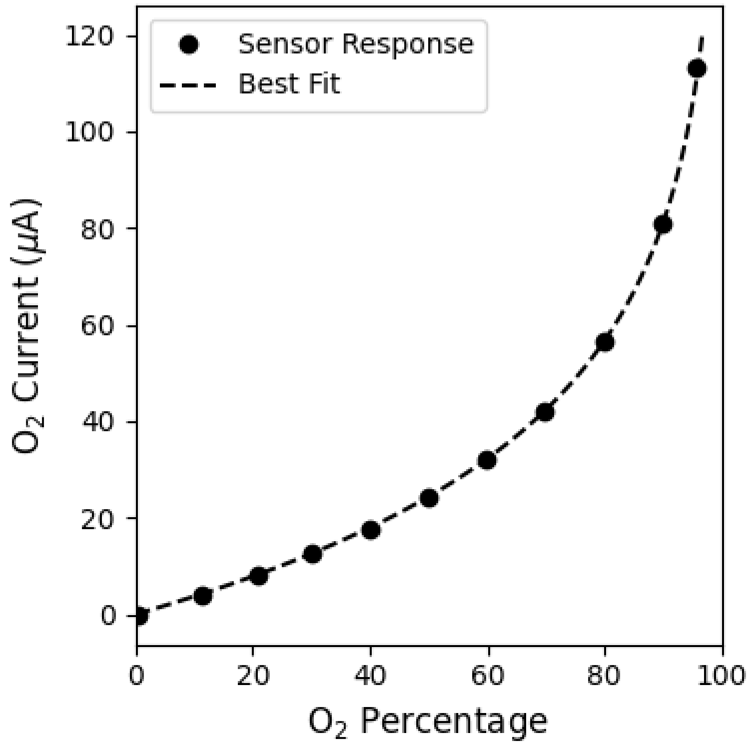
Oxygen Sensor Representative Data



$$I_{sensor} = -k \ln\left(1 - \frac{C_{O2}(0)}{C}\right)$$

$$k \sim 35\ \mu A$$

Saturation occurs at high oxygen concentration

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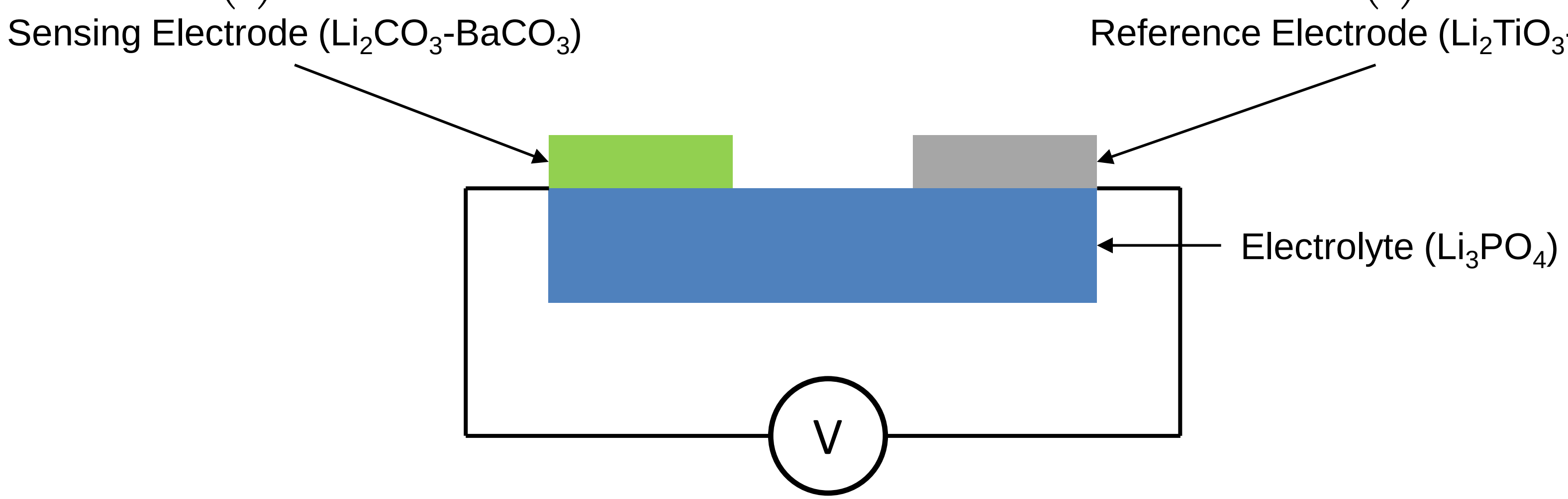
Potentiometric Carbon Dioxide Sensor

O_2, CO_2, Au | Li_2CO_3-$BaCO_3$ | Li_3PO_4 | Li_2TiO_3-TiO_2 | Au, CO_2, O_2

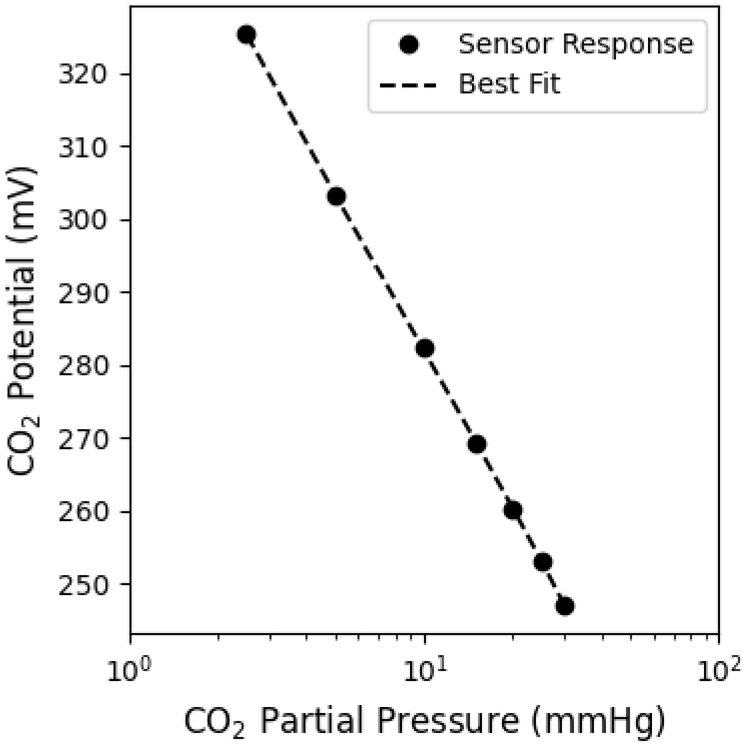
$$2Li^+ + CO_2 + \left(\frac{1}{2}\right)O_2 + 2e^- \leftrightarrow Li_2CO_3$$

$$Li_2TiO_3 \leftrightarrow 2Li^+ + \left(\frac{1}{2}\right)O_2 + 2e^- + TiO_2$$



$$E_{cell} = E^0_{cell} - \frac{RT}{2F}\ln\left(\frac{P_{CO_2}}{P_0}\right)$$

Carbon Dioxide Representative Data



$$E_{cell} = E_{cell}^0 - \frac{RT}{2F} \ln\left(\frac{P_{CO_2}}{P_0}\right)$$

$$V = V_0 - m \log\left(\frac{P_{CO_2}}{P_0}\right)$$

$$Slope\ (m) \sim 65 \frac{mV}{decade}$$

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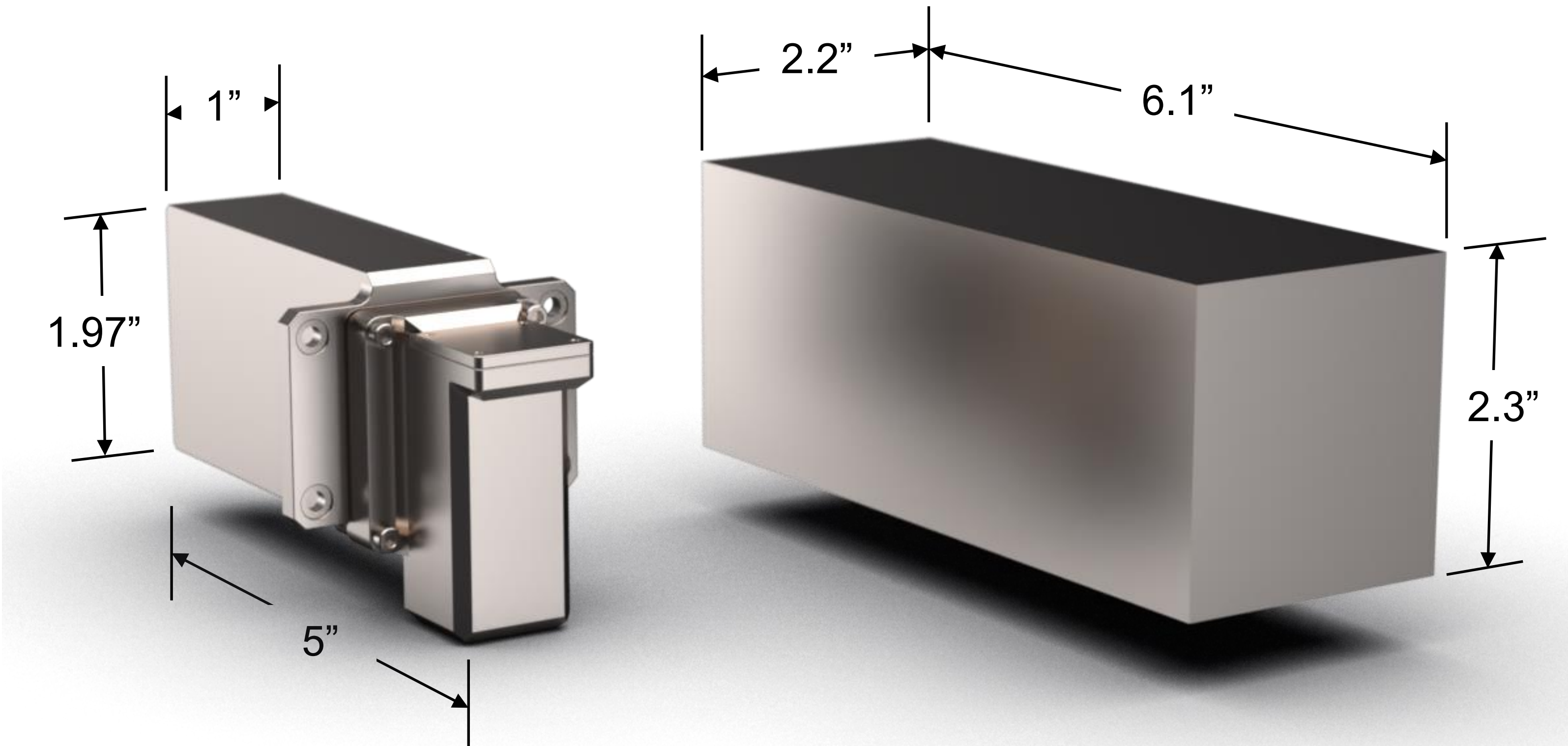
Sensor Assembly and Design

Size and Power

- Phase I Prototype is smaller than current NDIR sensors
  - Power consumption of approximately 1.8 W (5 V)



Phase I Prototype

NDIR Sensor Approximate Outer Mold Line

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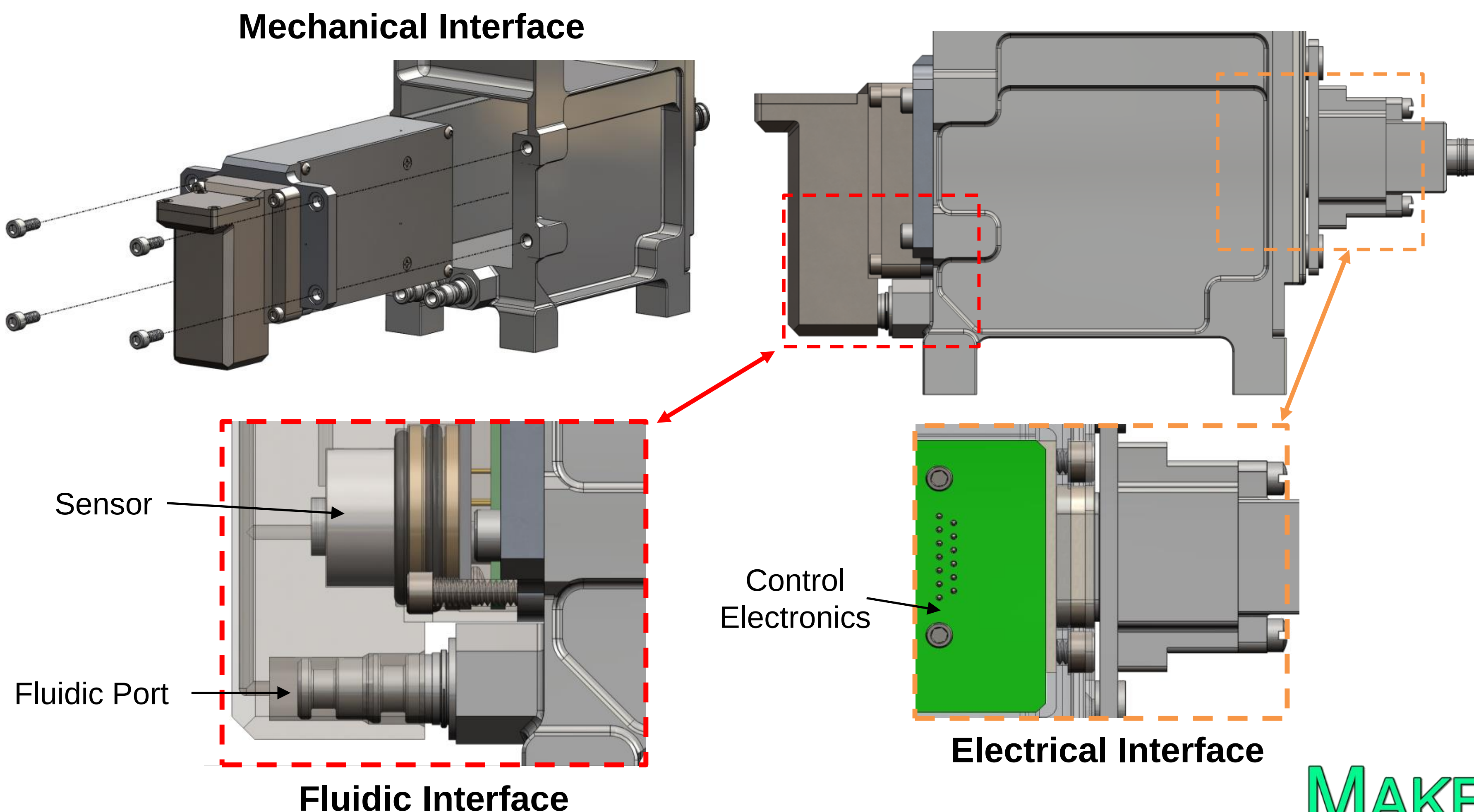
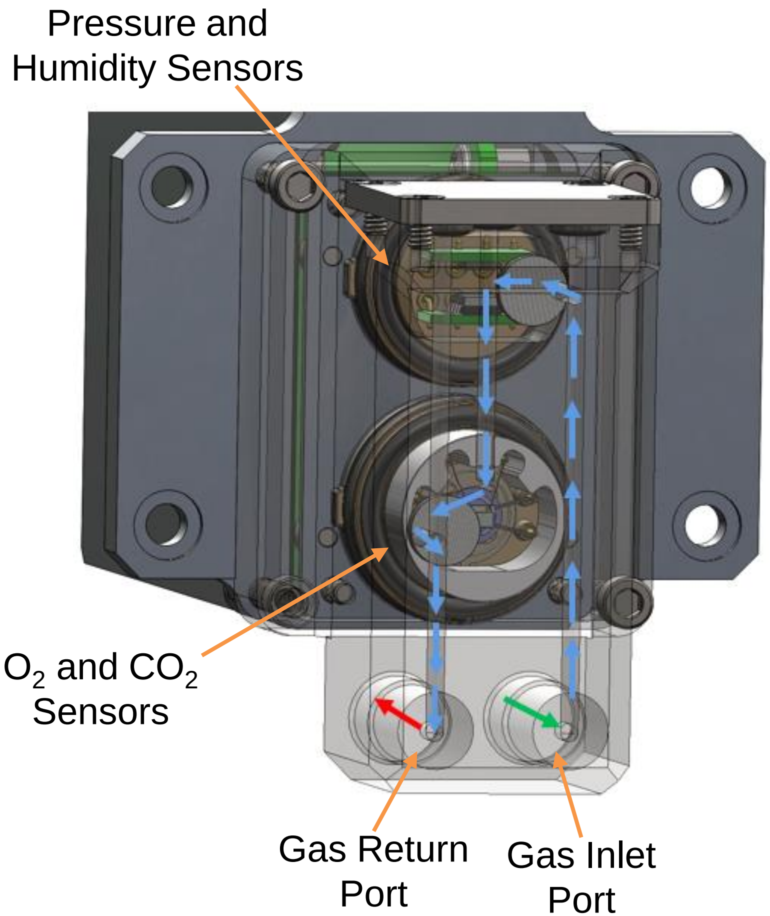
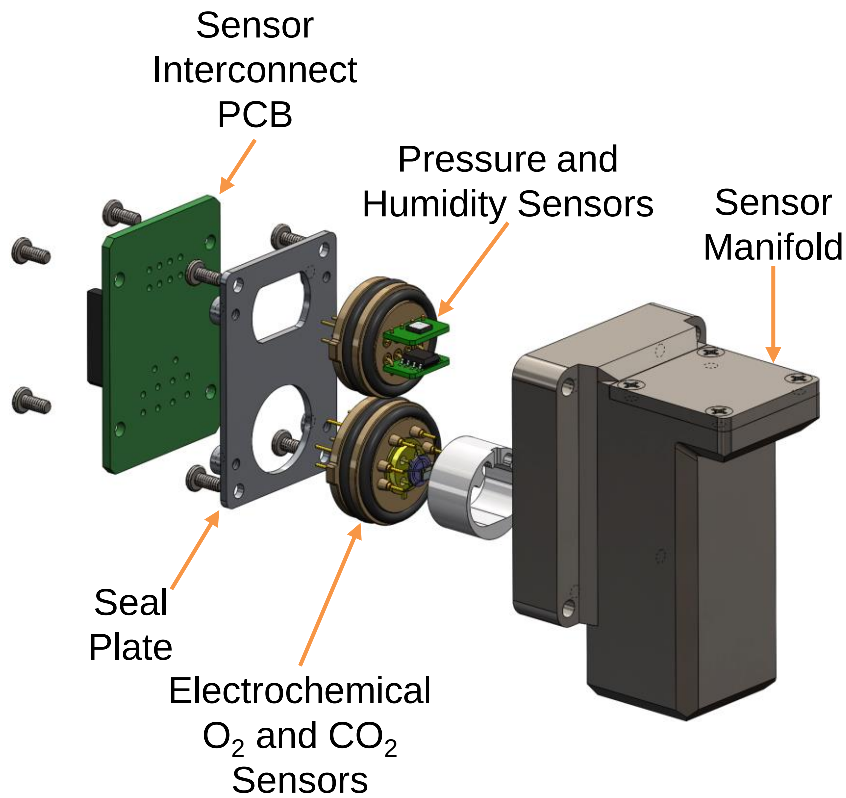
Preservation of Sensor Interfaces



Sensor Module





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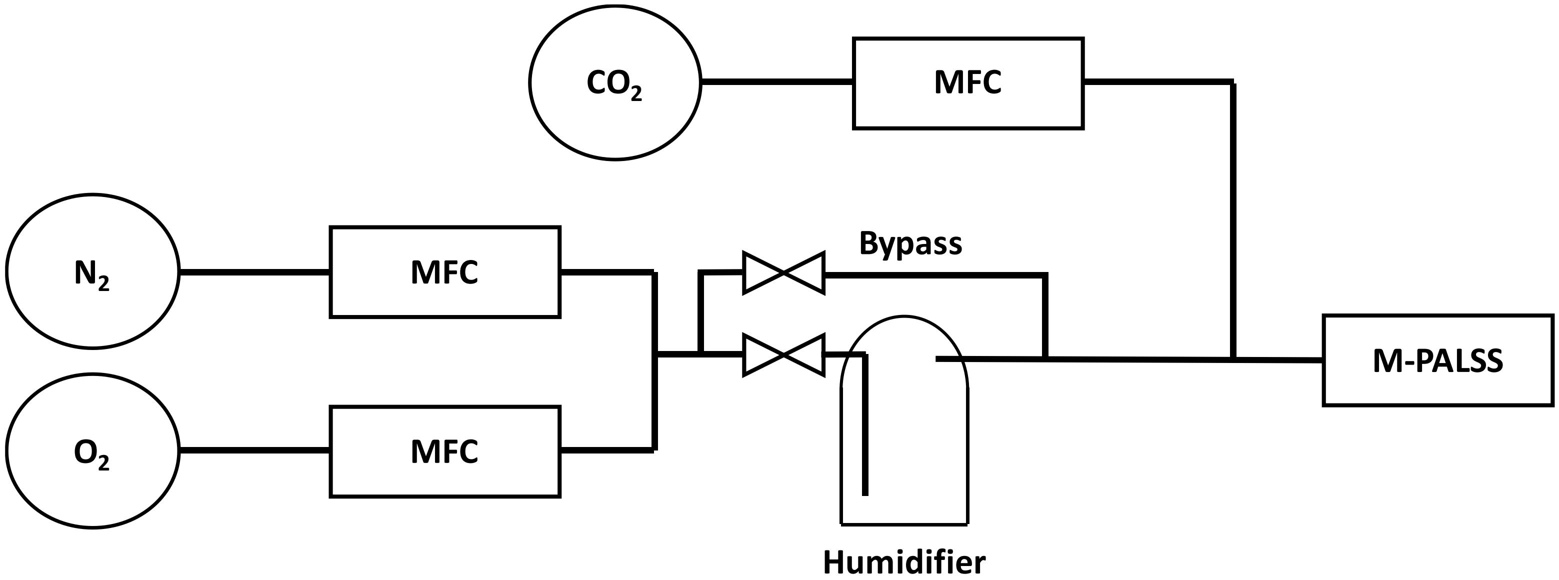
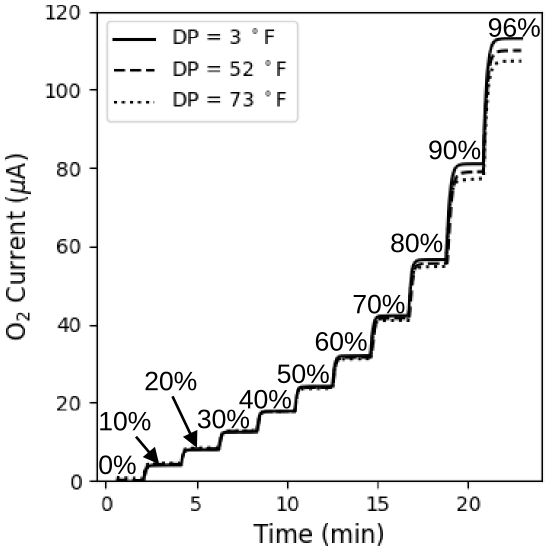
Prototype Testing and Performance

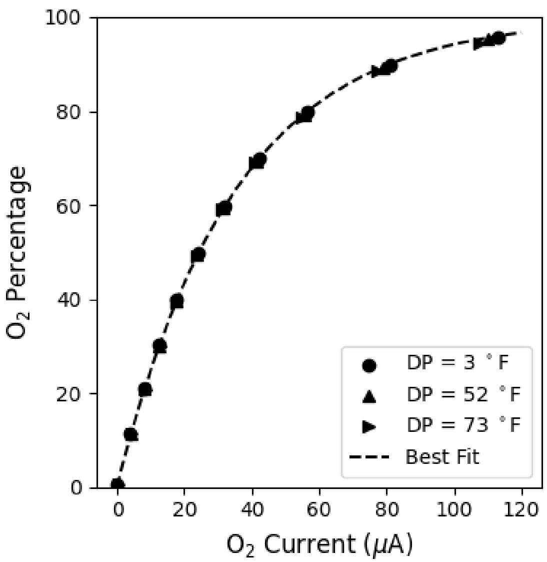
Gas Testing Configuration

- Certified gas mixtures are mixed using mass flow controllers (MFCs)
- Inline bubbler used to control the humidity



Oxygen Sensor Performance





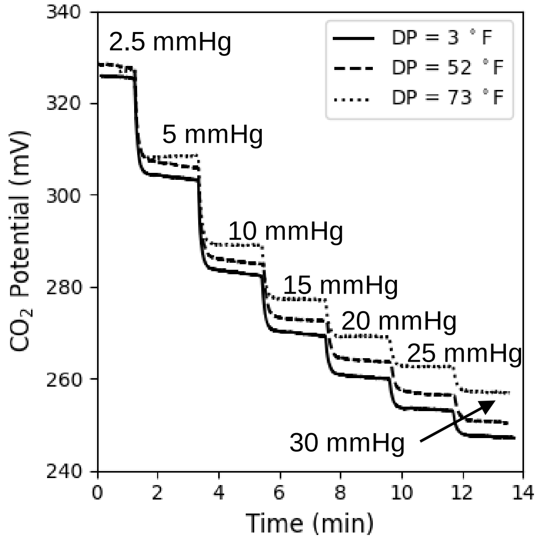
Testing conducted at 14.7 psia

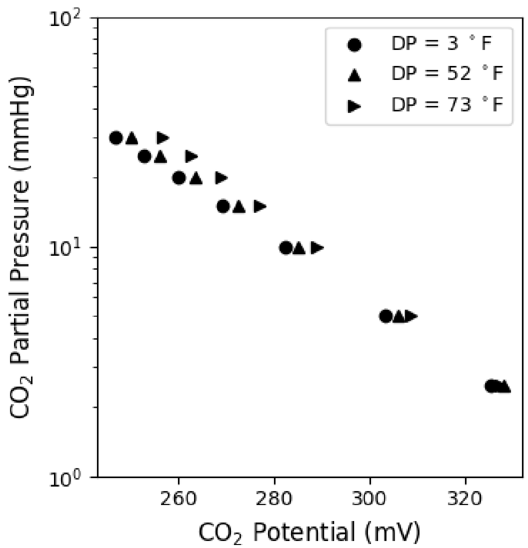
Response time t_{90}~3s

Annotated percentages are prior to humidification

$$\boldsymbol{O_2(\%) = 100\left(1 - e^{-\frac{I}{k}}\right)}$$

Carbon Dioxide Sensor Performance





Testing conducted at 14.7 psia

Response time t_{90}~12s

CO_2 sensor humidity interference is compensated by using the independent humidity sensor

$$P_{CO_2} = P_0\left(10^{-\frac{V-V_0}{m}}\right)$$

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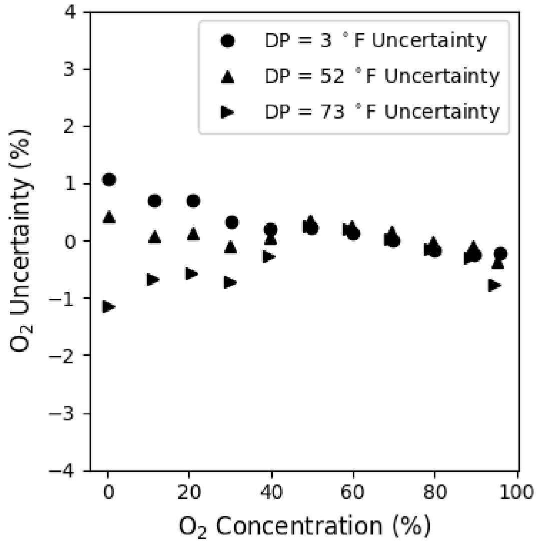
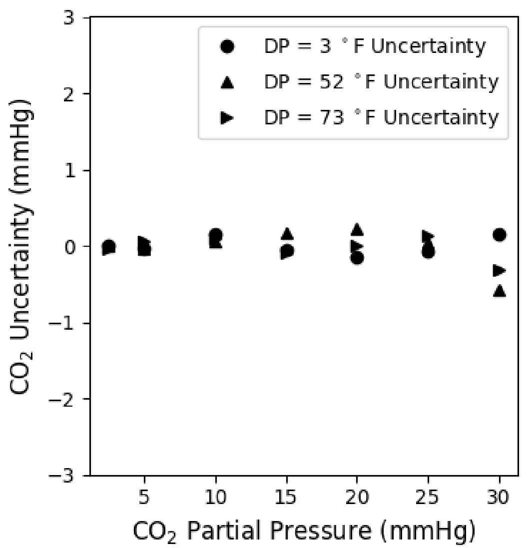
Measurement Uncertainty





O_2 sensor meets target requirements of ±1% with exception 0% O_2

CO_2 sensor meets target requirement of ±0.3 mmHg with exception of 30 mmHg after humidity correction

$$P_{CO_2} = P_0 \left(10^{-\frac{V - V_0(RH)}{m(RH)}} \right)$$

Conclusion and Future Work

- Work presented here completed as part of NASA Phase I SBIR Contact 80NSSC22PB085
  - Phase II work is ongoing
- Solid-state microsensors packaged into a prototype that preserves interfaces of current NDIR CO_2 sensors and meets target measurement accuracy
- Next steps of development are focused on meeting all the requirements for spaceflight and integration with the PLSS

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