SILICON CARBIDE PRESSURE SENSORS FOR VENUS ENVIRONMENT

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Motivation

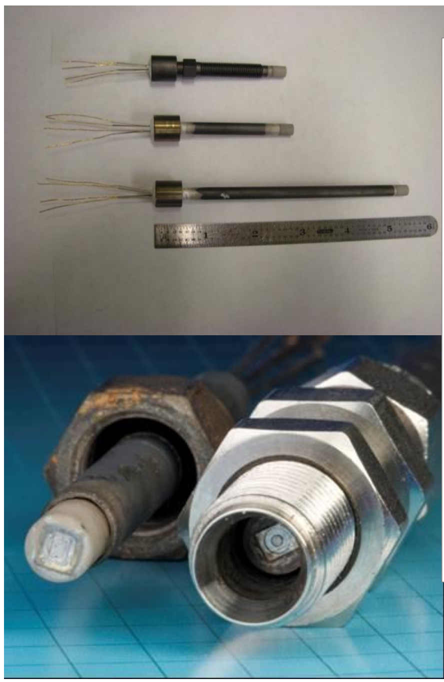
Interest in Venus has been stimulated by the ongoing debate about Earth's planetary evolution, particularly in regards to its climate, and NASA has proposed a flagship mission to Venus to be launched in the near future. Quantifying how the Venus evolution ran its course will greatly aid researchers trying to model Earth's climate dynamics.

Objective

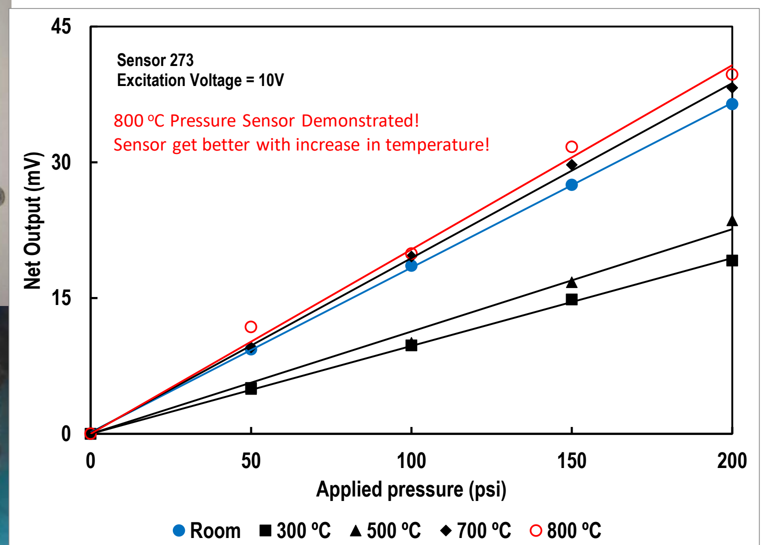
To determine the long-term robustness and survivability of semi-encapsulated piezoresistive silicon carbide pressure sensors in a simulated Venus atmosphere where pressure ~90 bar, temperature ~ 465 ºC, and aggressive reactive chemistry (SO_2, COS, etc). This is with the goal of infusion into future Venus science missions

Legacy SiC Pressure Sensors for Aero-Engine Applications Demonstrated at 800 ºC!

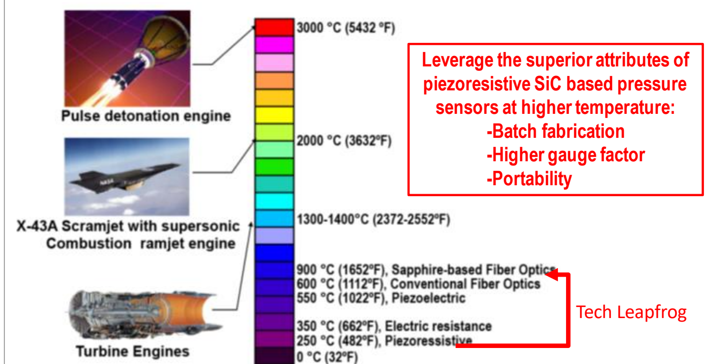
NASA SiC Pressure Sensors



Net Output vs. Static Pressure



Technology Enabling Space

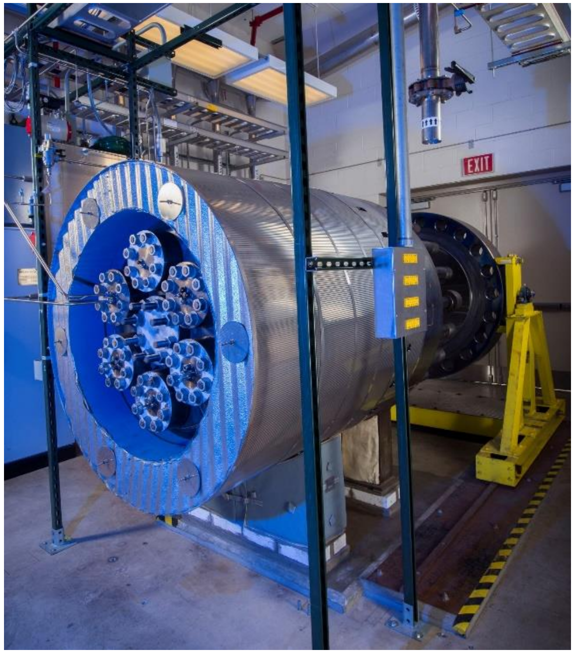


Alireza Behbahani and Kenneth Semega, "Sensing challenges for controls and PHM in the hostile operating conditions of modern turbine engine." AFRL-RZ-WP-TP-2008-2184

Approved for public release; distribution unlimited.

Infusion into Venus missions require material and structural considerations to survive the chemistry and high pressure

Glenn Extreme Environment Rig (GEER)



Simulated Venus Atmospheric Conditions

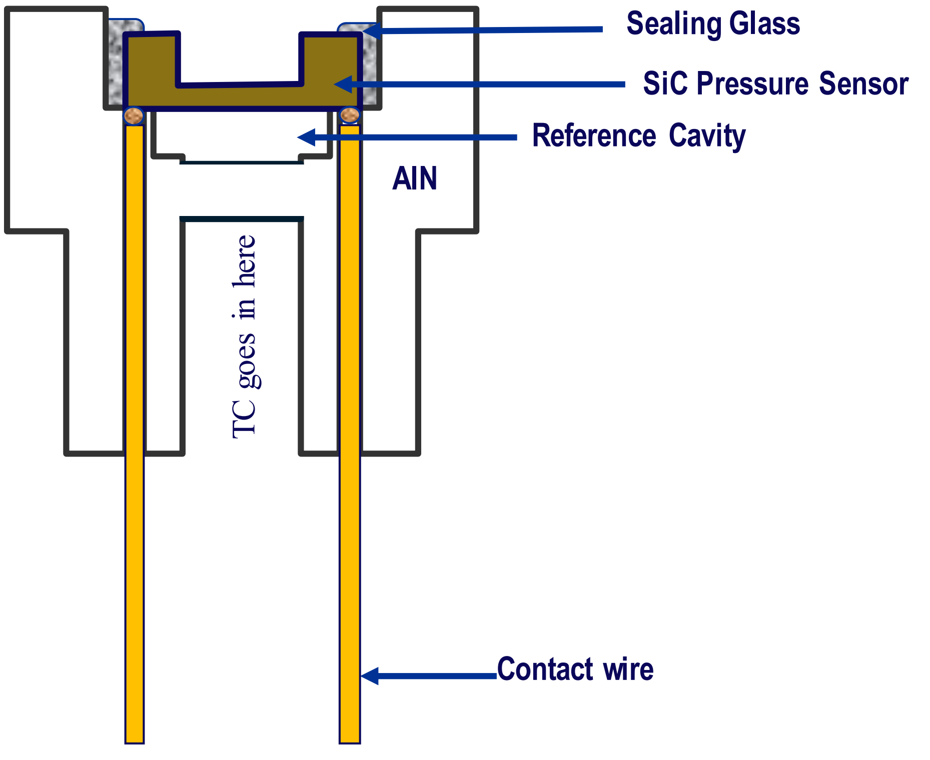
Temperature: 460 ºC +/- 10 ºC

Pressure: 1356 psia +/- 20 psia

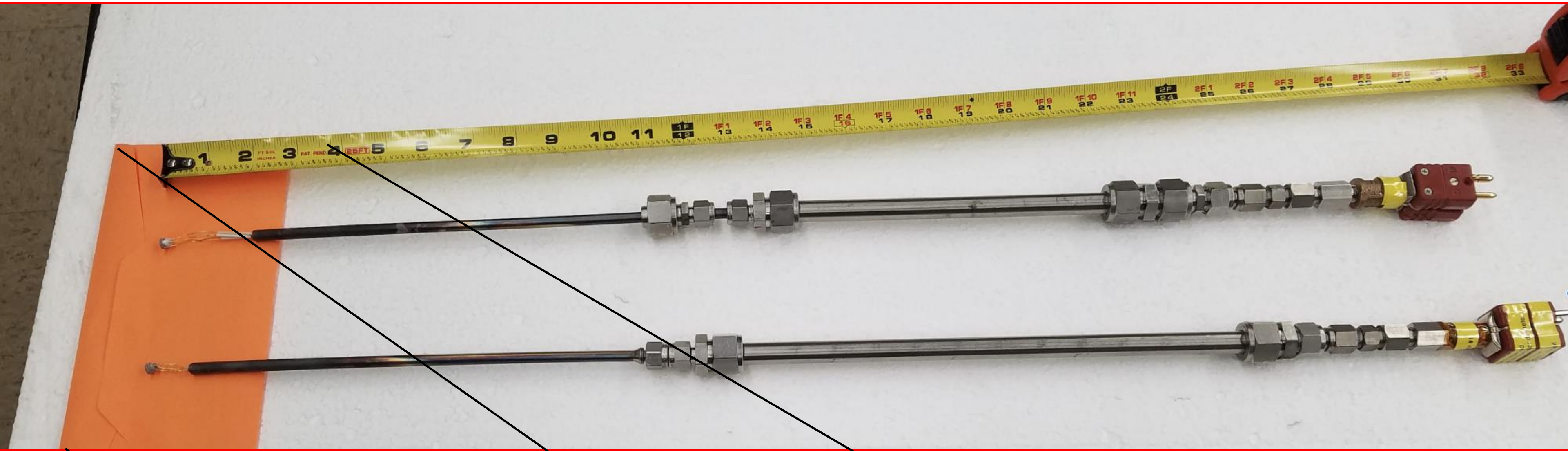
Chemistry: "Venus atmosphere" 96.5% CO_2, 3.5% N_2, 180 ppm SO_2, 12 ppm CO, 51 ppm COS, 2 ppm H_2S, 0.5 ppm HCl, 2.5 ppb HF

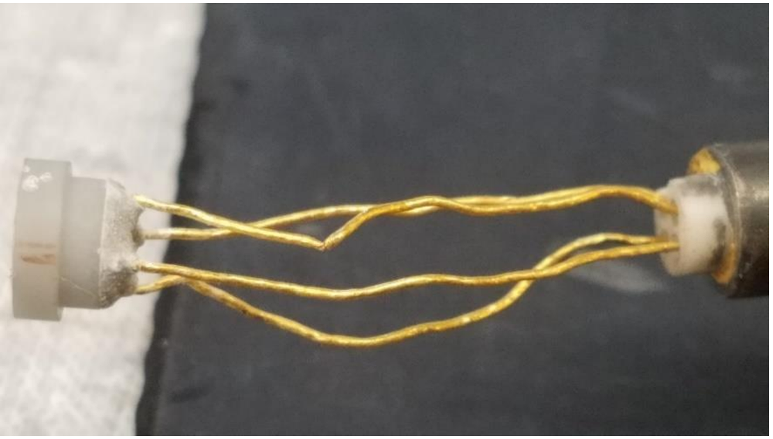
Range: SO_2 concentration range 100-200 ppm

Plug-In Type SiC Absolute Pressure Sensor



Plug-In Type SiC Pressure Sensor Extension for Insertion into GEER





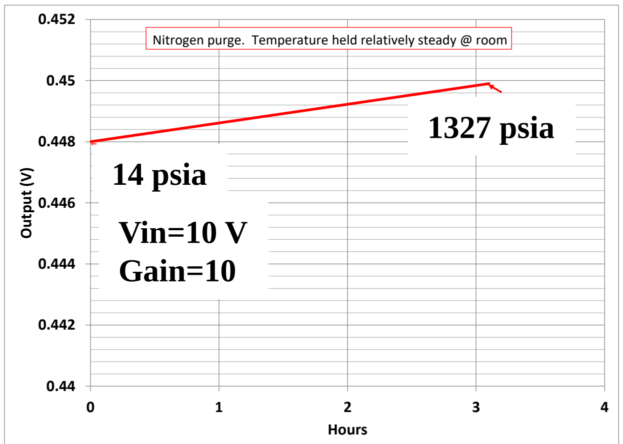
GEER Test Conditions

Start Up	**Vessel leak checked to 1400 psia at ambient temperature with high purity nitrogen. Next, the vessel will be purged of residual air and nitrogen by performing three pressure/vacuum cycles. The vessel will be left under vacuum after the last purge cycle in preparation for the specialty gas fill.** **Constituents of Venus atmosphere will be delivered to the vessel at ambient temperature starting with the vessel at negative pressure. The fill process will begin with CO_2 which will continue to flow continuously as the remaining specialty gas are filled. Specialty gases will be filled in the following order:** **Inlet valve closed to isolate the gas mixture within the vessel. Vessel temperature set point set to 456 C and the heaters will increase at 7 C/hr until the set point is reached.**
Shutdown	Upon completion of test, the vessel temperature set point will be reduced to 150 C. During cool down, the gas mixture will remain inside the vessel. Once the average gas temperature reaches 150 C, the mixture will be vented and the vessel will be thoroughly purged with dry nitrogen. The heaters will maintain an average internal temperature of 150 C during venting and purging. Once the purge is complete, the heaters will be turned off allowing the vessel to cool to ambient temperature. A small amount of nitrogen will be left inside the vessel during the final cool down to maintain positive pressure inside the vessel.

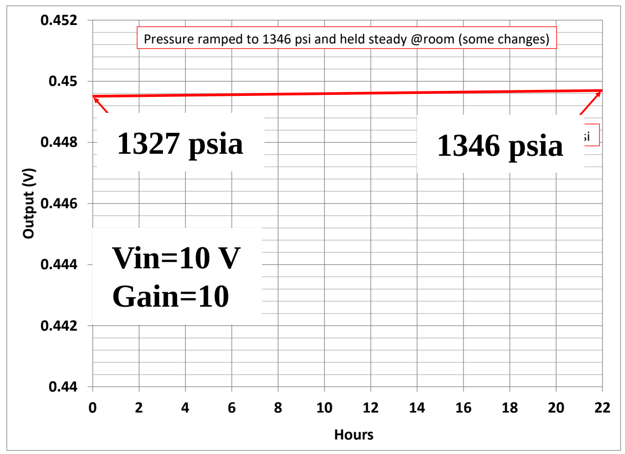
Room Temperature SiC Pressure Response in GEER Chamber

(Purge and Vent Steps at room temp)

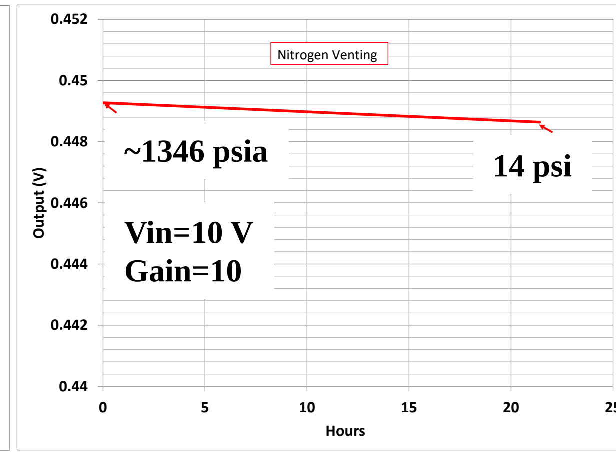
Pressure ramp-up



Ramp and Dwell

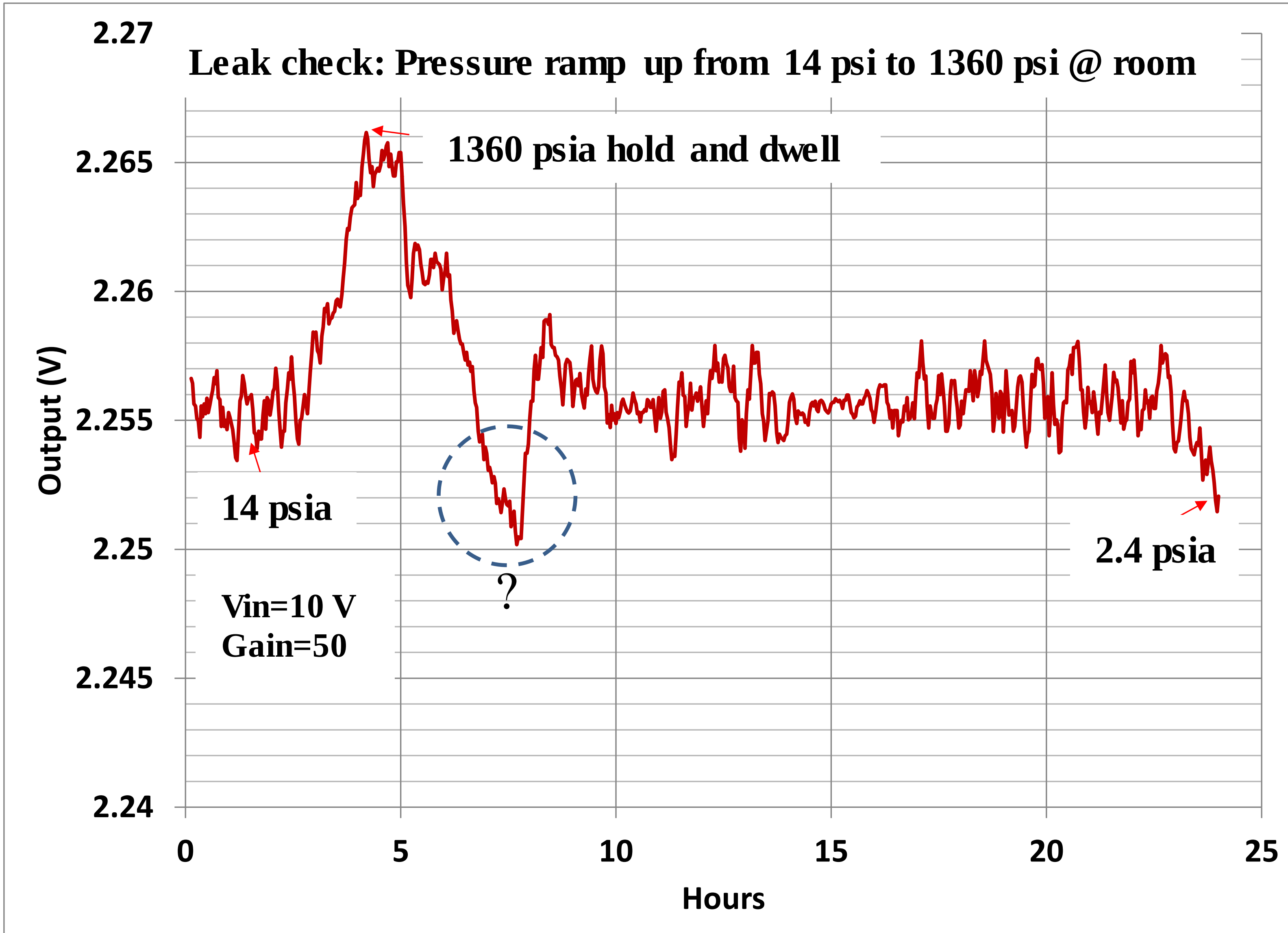


Ramp down

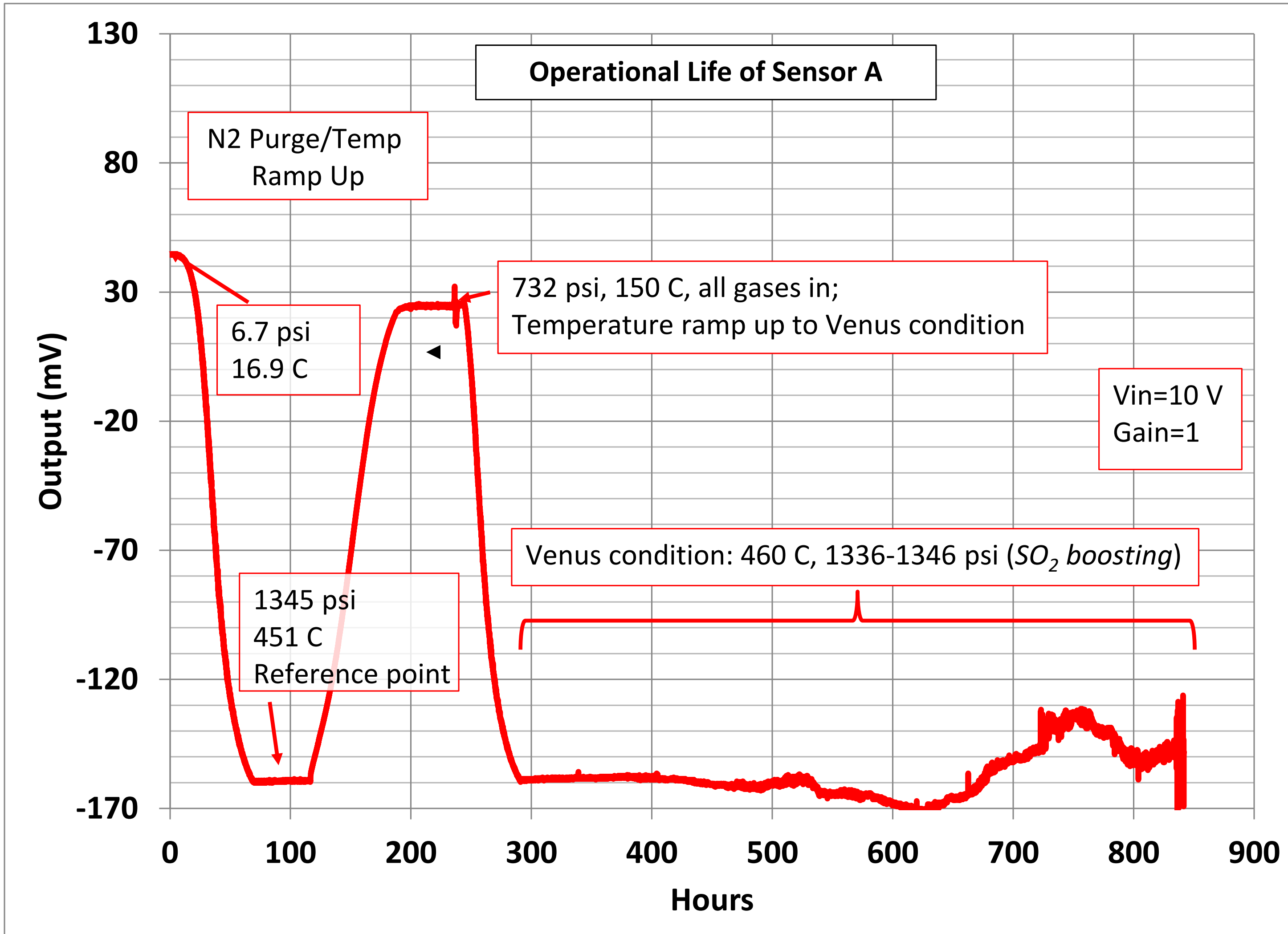


Sensitivity~0.21 μV/psi

SiC Pressure Sensor Response during GEER Chamber



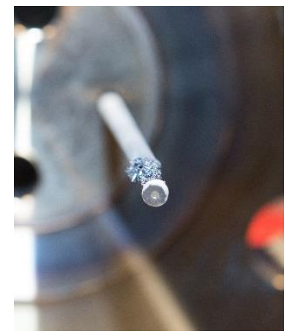
SiC Pressure Sensor Operational Life in GEER



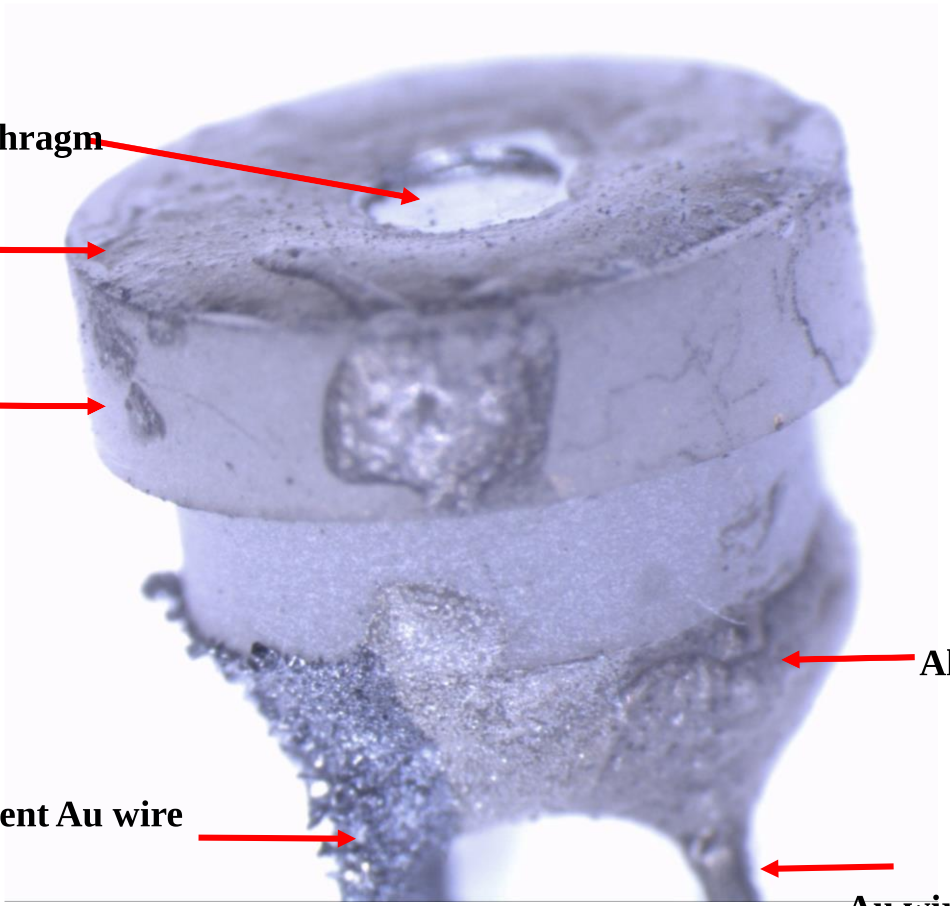
- Sensor reliably operational for 12 earth days
- Sensor survived 60 earth days (Test duration)

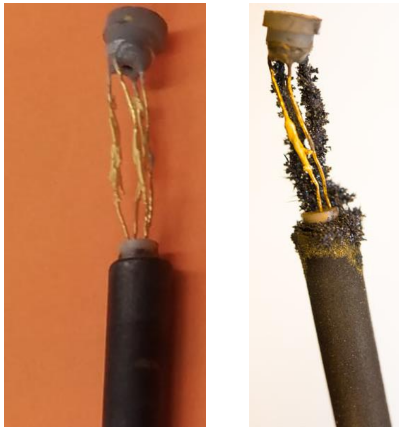
Post GEER Chamber Analysis



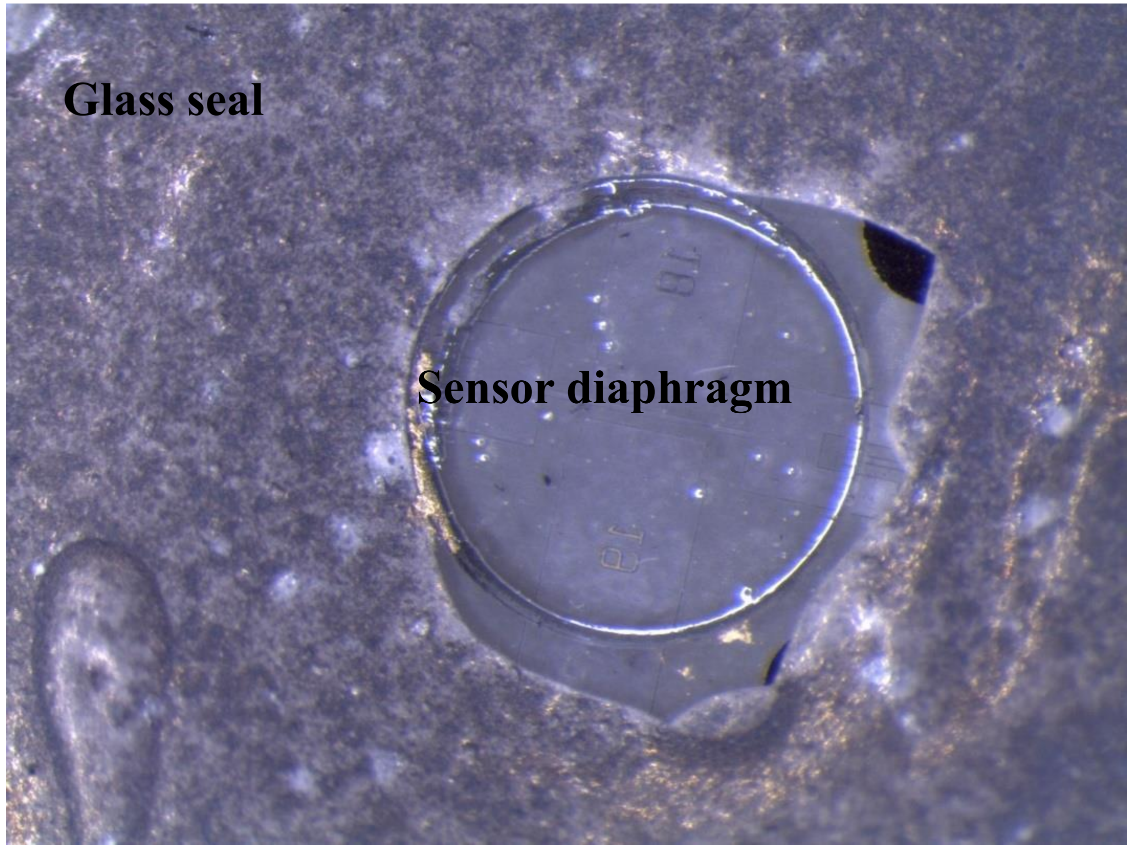

Post GEER Chamber Analysis





Post GEER Chamber Analysis

Sensor Top View

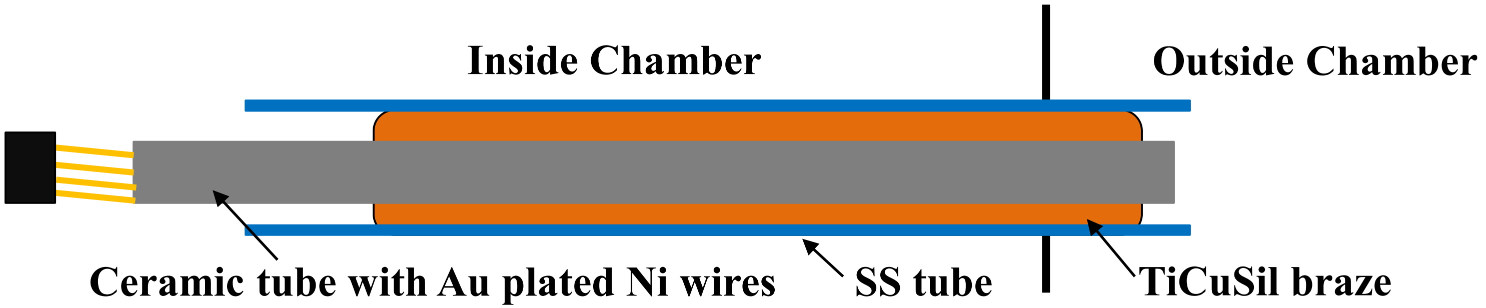


- Sealing Glass and sensor remained intact
- AlN header intact
- No loss of reference cavity

Key Observations

Two reaction paths:

1. TiCuSil braze material between ceramic tube and stainless steel tube
   - Cu and Ag sulfide crystals grow outward and eventually over the Au wires terminals.
   - Touching of the crystal between wires would result in shunt resistance.
2. Au-plated Ni wire in individual ceramic tube holes
   - Ni diffuses out of Au plating and reacts with SO_2 to form nickel sulfide.
   - Continued consumption of the Ni will result in gradual increase in resistance and sensor output



Materials Tested in Simulated Venus Atmosphere

Table 4 Tested Materials with Corresponding Outcomes

Devices	Materials	Outcome
Electronics Packaging	Pb	PbS
	Al_2O_3	No reaction
Insulation	CaO	$CaSO_3$, $CaSO_4$
SiC Electronics	Pt	PtS; fibers when present as thin film
	Pt (in the presence of Au)	PtS spheres
	Au	No reaction, but mobile
	Ir	No reaction, but mobile
	SiC	No reaction
	SiO_2	No reaction
Feedthrough Materials	Cu	Cu_2S crystals
	Ni	NiS crystals
	CuBe	Cu_2S crystals; Cl found on surface
SiC Pressure Sensor	Kovar (Ni-Co-Fe)	NiS, Fe_xO_y
	AlN	No reaction
	Ag-Cu Braze	segregation into Cu_2S and Ag; Ag mobile
GEER Components	Inconel 625 (Ni-Cr-Mo-Fe)	NiS, Cr_xO_y
	304 SS	Mirror finish, low corrosion rate
	Al foil/Mg doped	MgO on surface, MgF inner layer, Al bulk no reaction

Lukco, D. et al, Earth and Space Science, doi.org/10.1029/2017EA000355

Summary, Conclusion, and Future Plans

- Sensor room temperature test shows good linear response to pressure
- Sensor stable and reliably operational for ~12 earth days
- Sensor physical structure survived 60 earth days of testing
- Primary failure mechanism : Gradual NiS formation on Au-plated Ni wire resulted in changes in wire resistance
- Long term reliable operation beyond 12 days is in the works
- Plan to integrate with temperature sensor and electronics in progress
- Open to collaboration for infusion into any Venus science mission architecture

Thank You!