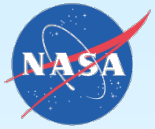

High Temperature Rad-Hard Electronics, Atmospheric Measurements, and Sensor Systems for Venus Exploration and Other Planetary Missions

POC:
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New Frontiers Drivers: Atmospheric Characterization

- The Decadal Survey identifies the Venus In-situ Explorer (VISE) mission as a New Frontiers high priority to, in part,

  "Understand the physics and chemistry of Venus's atmosphere, especially the abundances of its trace gases, sulfur…" and "…Venus's atmosphere down to the surface."

- The VISE **"mission architecture consists of a lander that acquires atmospheric measurements during descent, and then carries out a brief period of remote sensing and in situ measurements on the planet's surface"** and **"…focuses on the detailed characterization of the surface, deep atmosphere and their interaction..."**
  - Answering gaps in atmospheric science require ***"…in situ measurements, such as can be performed during atmospheric transit by landers like VISE, using balloons, and/ or drop sondes and probes"***.
  - An important question is **"What are the elemental …compositions of species in Venus's atmosphere, especially the …nitrogen-, hydrogen-, carbon- and sulfur-bearing species"**.
- VEXAG Exploration Investigations III.B.3-4 includes determination of **"the abundances and altitude profiles of reactive atmospheric species (OCS,...SO_2,..HCl, HF)…H_2O"** and as well as CO. The presence of SO_x is thought to provide potential geological information on the presence of volcanoes, and NO to indicate lightening.

IN-SITU ATMOSPHERIC MEASUREMENTS OF A RANGE OF TARGETED SPECIES FROM THE UPPER ATMOSPHERE TO THE SURFACE OF HIGH RELEVANCE TO NEW FRONTIERS

New Frontiers Drivers: High Temperature Electronics

- Decadal notes that technology development "is critical for future studies of the inner planets" and suggests to possibly "expand incentives to include capabilities for surface access and survivability for challenging environments such as Venus's surface…". with "the potential to dramatically enhance the scope of scientific exploration that will be possible...". *A major technology risk for missions near/on the Venus surface is the operation of electronics/sensor systems for sustained periods.*
- **Decadal notes that "*inclusion of demonstration technologies on a VISE mission would be justified"*** and a recent VEXAG finding "encourages PSD to explore the feasibility of STMD supporting technologies applicable to Venus missions. Some technologies could benefit from space demonstrations and could be prime candidates for consideration in the Technology Demonstration Mission program".
- VEXAG emphasizes "**Development of high-temperature electronics, sensors…designed for operating in the Venus ambient would be enabling for future missions".** and **"Specific high-priority technologies for short-duration (hours to days) missions to Venus"** include "Development **of high-temperature electronics for instruments and communication systems that will survive temperatures of up to 470°C for both short-and long-duration missions,** so that cooling systems are not required for sustained surface lifetimes".

HIGH TEMPERATURE ELECTRONICS FOR SUSTAINED VENUS SURFACE OPERATION ARE A STRONG CANDIDATE FOR A NEW FRONTIERS TECHNOLOGY DEMONSTRATION.

A Combined System Proposed: Venus In-situ Atmospheric Measurement Instrument Package (VIAMIP) Based on a High Temperature Microsensor Array and Electronics

Packaging and Interface Requirements for Venus Flyable MicroSensor Array (NASA Phase II SBIR NNX13CC79C)

Basic Requirements/Specifications

Characteristic	Parameter
Power Consumption (surface lander)	<100 mW (no heating of sensor needed)
Power Consumption (drop sonde)	< 1000 mW (sensor heating required)
Power sources and input voltage	TBD - baseline 4-5 VDC battery power
Gas species	CO, NO, OCS, SOx, H_2, O_2, H_2O, HF, HCl
Concentration Range	Typically 0-100 PPM
Mass	Less than 200 gms
Sensor time response	Less 5 sec
Volume	4 x 4 x 4 (LxWxH cm) for sensor array
Vibration	Launch and landing capable
Temperature	460^{o}C minimum capability
Pressure	95 atm maximum, space vacuum minimum

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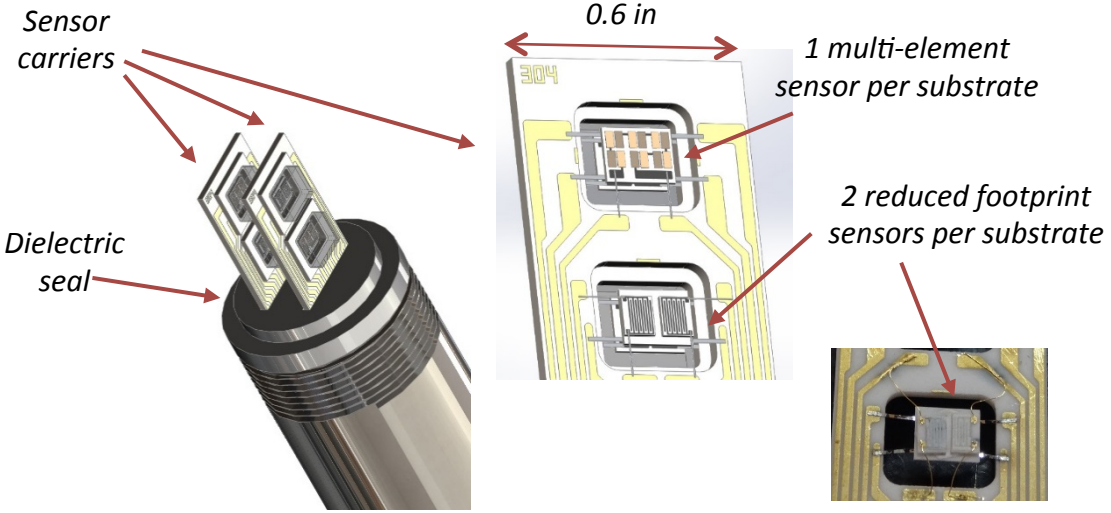
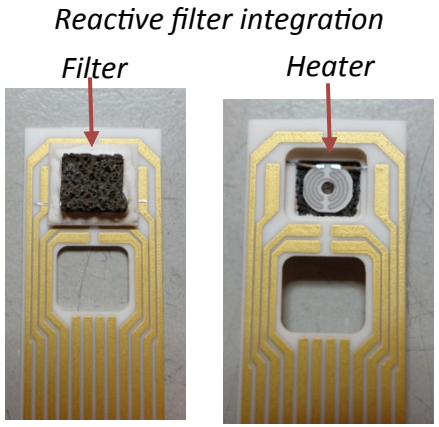
Multi-Sensor Array Approach

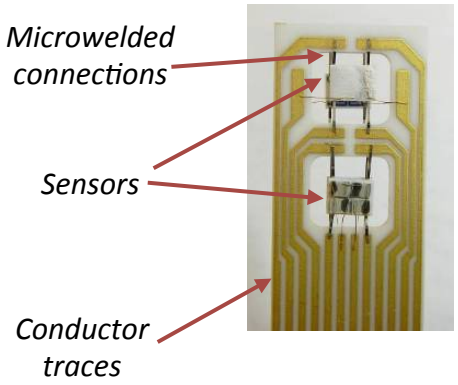
- *Each sensor carrier holds up to 4 sensor substrates using front and back conductor traces*
- *Resistive and single element sensors have reduced footprint enabling 2 sensors per substrate*
- *Typically 3 species per slot, enabling 12 sensors using two sensor carriers*





Multi-sensor array

Ceramic core and sensors resist extreme thermal stress.



Printed conductors on sensor carrier enable robust sensor connections and interconnection to electronics module.

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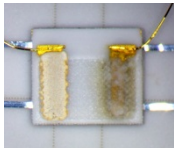
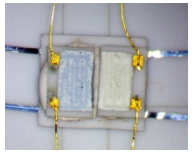
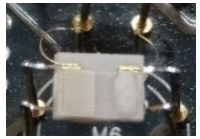
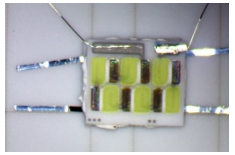
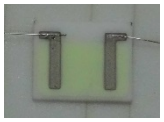
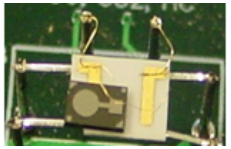
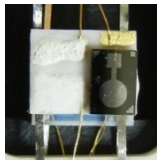
Sensor Fabrication and Testing

Developed Sensors

Species	Sensor Technology	Acid Filter	Reactive Filter For Improved Selectivity	Operating Temp (°C)	Range (PPM)
CO	TiO_2	TBD	Not needed	500	0-50
SOx	Ag based or alkaline-earth-ion electrolytes	Yes	Yes for total sulfur measurement	500	0-200
OCS	TiO_2	Yes	Alumina filter for thermal decomp of CO	500	0-50
H_2	SiC Diode	Yes	Yes to differentiate from HF	400	0-30
HF	SiC Diode	No	NO	500	0-50
HCl	Poteniometric Zeolite	No	TBD	500	0-5
NO	PtY and/or WO_3 on YSZ	Yes	Reduce CO impact	500	0-30
NO	CrO_3/WO_3 on p-n junc	TBD	No	500	0-30
O_2	ZrO_2	Yes	Not needed	500	0-50
H_2O	Differential Bias ZrO_2	Yes	Not needed	500	0-100
HCN	Poteniometric Zeolite	No	TBD	400	TBD

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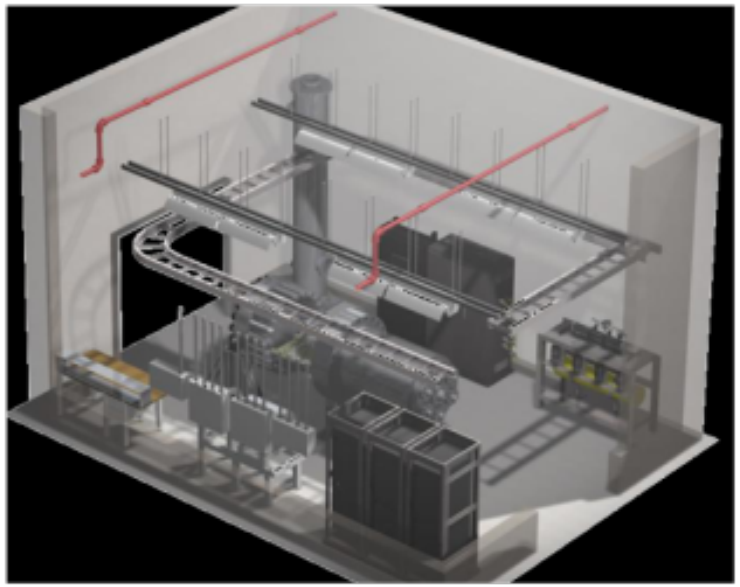
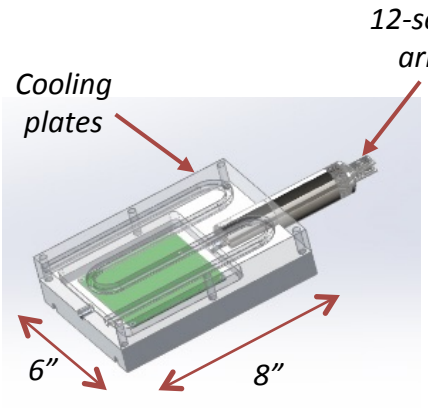
Perform Field Tests at NASA Glenn GEER Facility

- NASA Glenn Extreme Environment Rig (GEER) provides realistic Venus atmosphere simulation
- Space Act Agreement for access to facilities in progress
  - Testing at GEER starting 4th quarter FY16



Cooling plates keeps electronics < 250oC in GEER chamber at 460oC, simulating lander implementation



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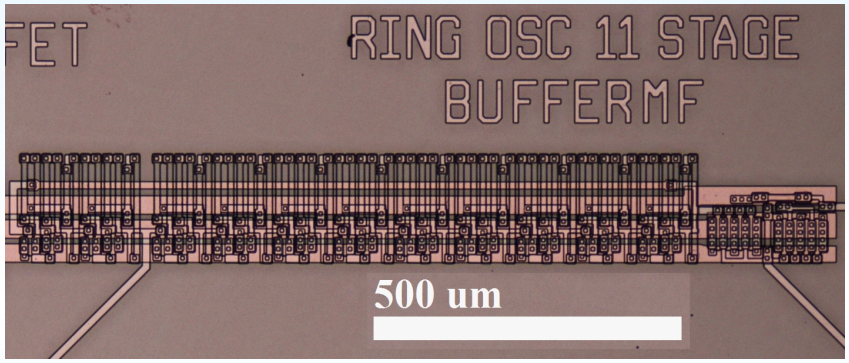
High Temperature Electronics

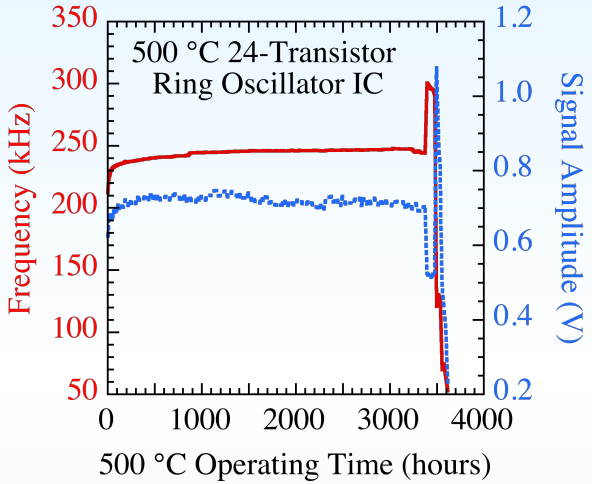
- ***Unique capabilities have produced the World's First Microcircuits at moderate complexity (Medium Level Integration) that have the potential for long-lived operation at 500˚C***
- **Circuits contain 10's to 100's of JFETs; An order of magnitude beyond a few JFETs previously demonstrated (which was recognized as one of NASA's Top Discovery Stories)**
- **Significant step towards more complex electronics operation in harsh environments and Smart Engine Systems**
- **Enables a wide range of sensing and control applications *at High Temperatures***
  - **In-package signal conditioning for smart sensors**
  - **Signal amplification and local processing**
  - **Wireless transmission of data**
- **Intended operational life at 500˚C of at least thousands of hours;**
  - **Verified in several circuits; Processing of new circuits on-going**
  - **Extensive process development experience provides confidence for long-life high temperature durability**
- **Direct pathway to more complex circuits identified and demonstrated**
- **SiC Processing Electronics are Intrinsically Rad-Hard**

Extended Operation of Integrated Circuits at 500 °C

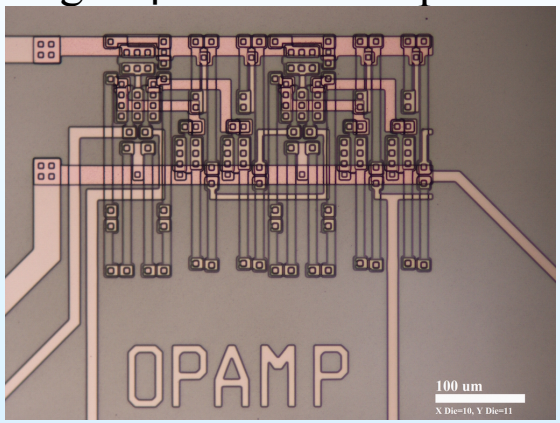
- **World's First Prolonged 500 °C Demonstrations of Multi-Level Interconnect IC's.**
  - Multi-Level Interconnect Enables Complicated (>100 Transistor) IC's.
  - Enables amplification, digitization, intelligence at the harsh-environment sensor.
  - Prolonged harsh-environment operation needed for insertion into useful applications.

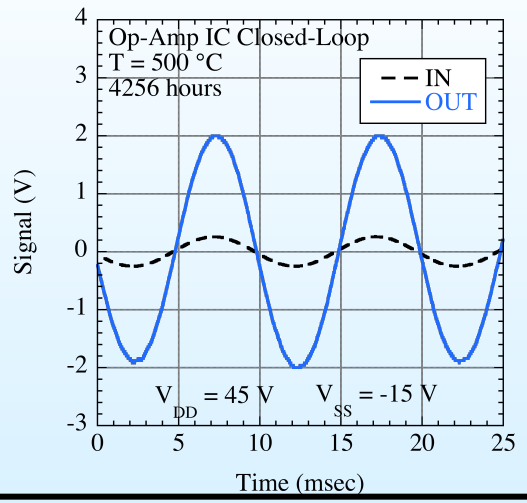
24-Transistor Ring Oscillator IC





2-Stage Operational Amplifier IC





FOUNDATION FOR HIGH TEMPERATURE COMPLEX CIRCUITS

DESIGN/BUILD APPROACH OF A BROAD RANGE OF CIRCUITS BASED ON THIS CORE TECHNOLOGY

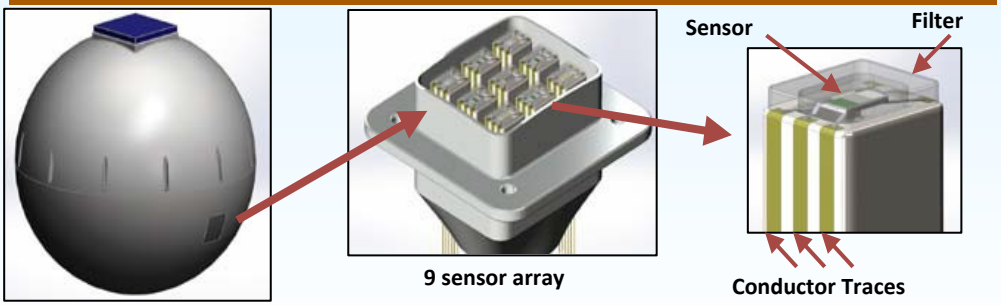
- **A tool-box of signal conditioning, processing, and communications circuits are being developed and demonstrated**
- **High temperature results are now available for some circuits. More processing runs and data to follow.**
- **Work could enable, e.g., a potential Venus Meteorological Station (PICASSO)**
- **Circuits now fabricated and being tested, or to be tested at 500°C:**

Circuit	Inputs	Outputs	Transistors, I/O Pads	Comments
4-Bit A/D	Analog voltage signal, optional external clock, output type select	4 bit parallel digital latch, pulse width modulated (PWM)	203 JFETs, 23 I/Os	Internal ring-oscillator clock circuit
4X4 Bit Static RAM	Read, Write, Data Lines, Address Lines	4 bit parallel digital latch, pulse width modulated (PWM)	220 JFETs, 30 I/Os	Address decoder, sense amplifiers
Source Separation Sensor Signal Transmitter	Capacitive sensor	Frequency modulated with address code	301 JFETs, 20 I/Os	Each sensor signal is tagged with unique address code
Ring Oscillators	Capacitive sensors	Frequency modulated signals (up to 500 MHz)	10-12 JFETs, 6 I/Os	On-chip large transistors for power amplification
Binary Amplitude Modulation RF Transmitter	Low power binary signal	High-Power RF signal to antenna		Could connect with PWM from A/D
Op Amp, 2-Stage	Differential	Voltage gains to 50 w/ on-chip resistors	10 JFETs	For piezoelectric SiC pressure sensors
4-Bit D/A	4 digital	1 analog	20 JFETs	

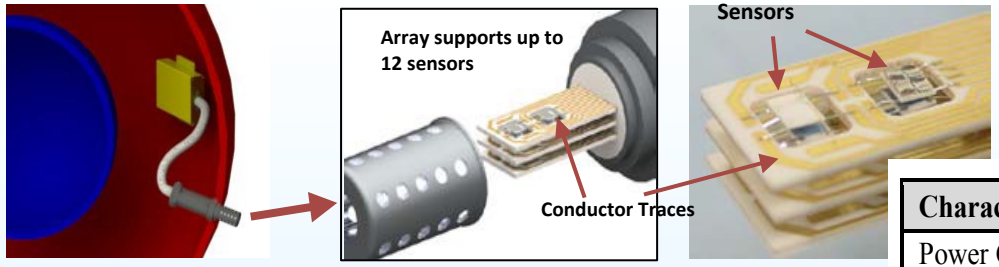
COMBINED SYSTEM ON A DROP SONDE/LANDER:

VENUS IN-SITU ATMOSPHERIC MEASUREMENT INSTRUMENT PACKAGE BASED ON HIGH TEMPERATURE MICROSENSOR ARRAY AND ELECTRONICS

DROP SONDE: Array design targets flush mounting



Lander Module: Array design maximizes exposure to atmosphere



Implementation in either drop sonde or lander investigations.

Basic Requirements/ Specifications of Combined System

Characteristic	Parameter
Power Consumption (surface lander)	<100 mW (no heating of sensor needed)
Power Consumption (drop sonde)	< 1000 mW (sensor heating required)
Power sources and input voltage	TBD - baseline 4-5 VDC battery power
Mass	Less than 200 gms
Sensor time response	Less 5 sec
Volume	4 x 4 x 4 (LxWxH cm) for sensor array
Vibration	Launch and landing capable
Temperature	460°C minimum capability
Pressure	95 atm maximum, space vacuum minimum

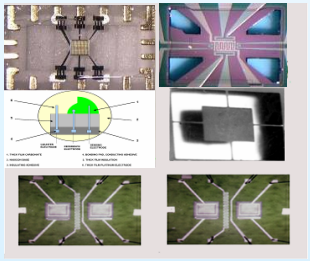
Drop Sonde/Insitu Measurements Complements Other Venus Technology Development

NASA GRC: Seismometer And Meteorological Network Concept

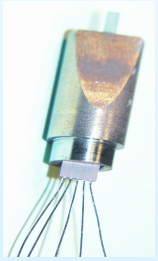
- Simple High Temperature Electronics Operational at 500°C
- A Range Of High Temperature Sensor Systems Already Exist For 500°C Operation
- Provide Measurements Of The Size-frequency Distribution Of Seismic Events
- Provide Correlation Between Observed Planetary Events/Changes In Weather Conditions

Surface meteorology with temperature, wind speed and direction, and pressure combined with seismometry

High Temperature Electronic Nose (Chemical Species)

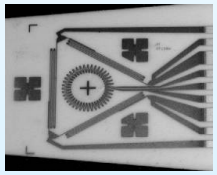


HOTProbe (Wind flow, Pressure, Temperature)



Pressure Sensor (Pressure)

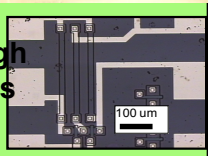
Physical Sensor Array (Temperature, Heat Flux, Flow)



500° C Operational

Seismometer Components

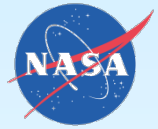
+ World Record High Temp Electronics



In Development

SUMMARY

- New Frontiers VISE Mission Calls for Characterization of Venus Atmosphere From the Upper Atmosphere to the Surface, with Technology Demonstrations of Technologies such as High Temperature Electronics of High Relevance
- A Multiparameter Chemical Sensor Array Matured for a Range of Venus Relevant Species
- High Temperature Electronics of Moderate Complexity Have Shown Extended Operation at Venus Relevant Temperatures
- Combined System of Chemical Sensors and High Temperature Electronics Could Not Only Provide Enhanced Measurement Capabilities but also Serve as a Technology Demonstrator for New Venus Capabilities and Future Missions
- A Range of Other Sensor Systems of High Maturity: Pressure, Temperature, Physical Measurements
- Relevance Beyond Venus Applications: High temperature/pressure chemical microsensors and rad-hard electronics could be applied in other solar system research including the Gas Giants
  - For example, the New Frontiers 5 Saturn Probe mission seeks in-situ measurements with probes at depths of up to ~10 bar, to “provide atmospheric elemental … abundances, including methane abundances.” Harsh environmental limitations restrict these measurements

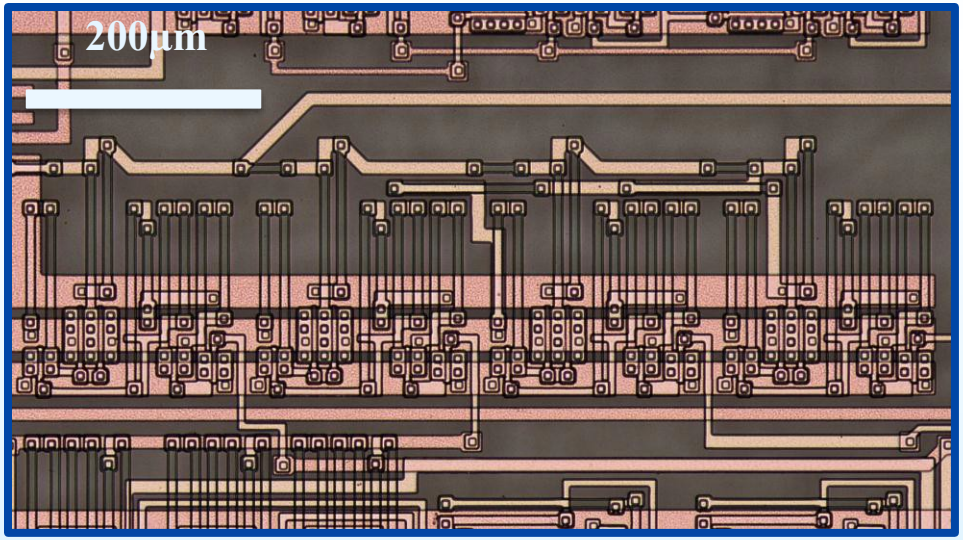


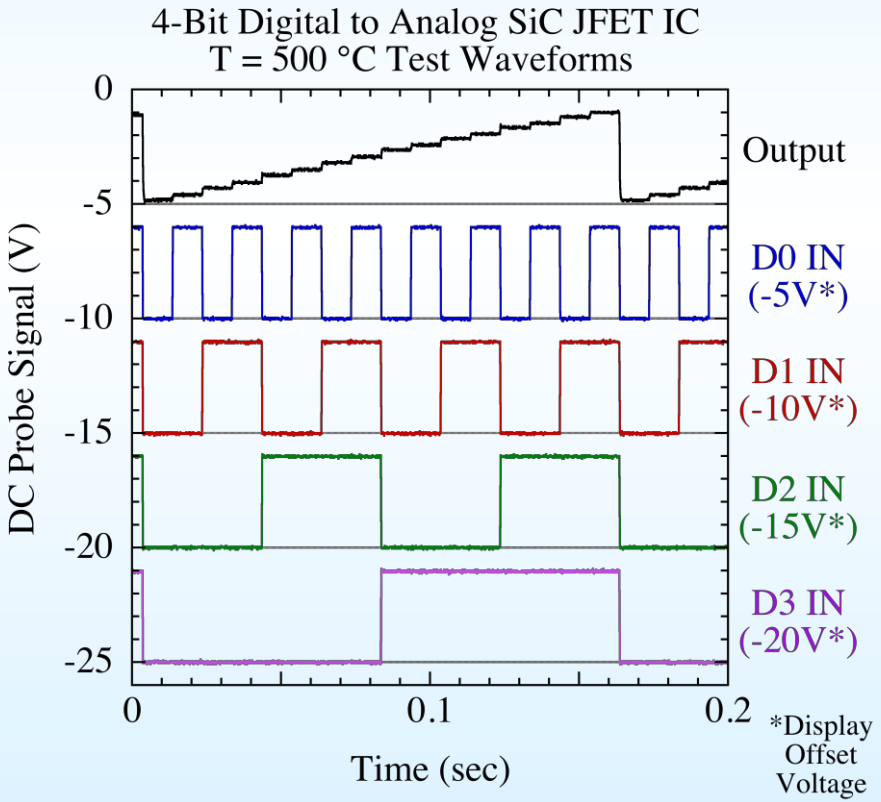
Back-Up Slides

Digital to Analog (D/A) Converter

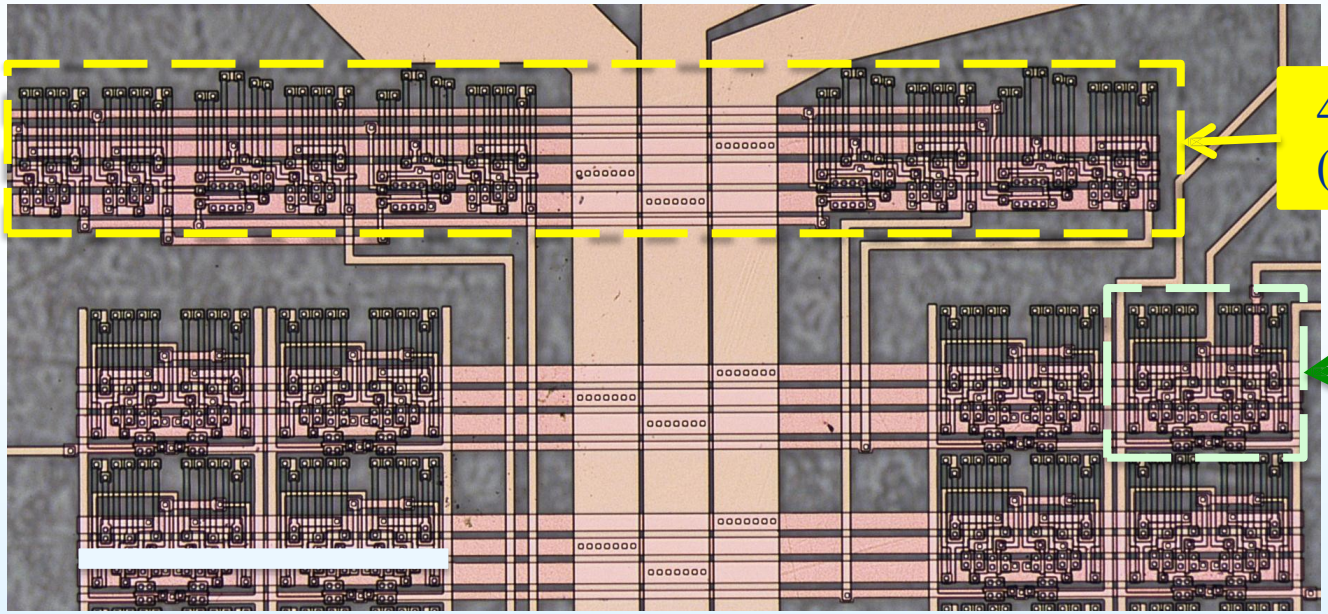
- A/D can provide in-package digitization of sensor
- Future versions to provide higher bit count

4-Bit Digital to Analog Integrated Circuit (16 SiC JFETs)

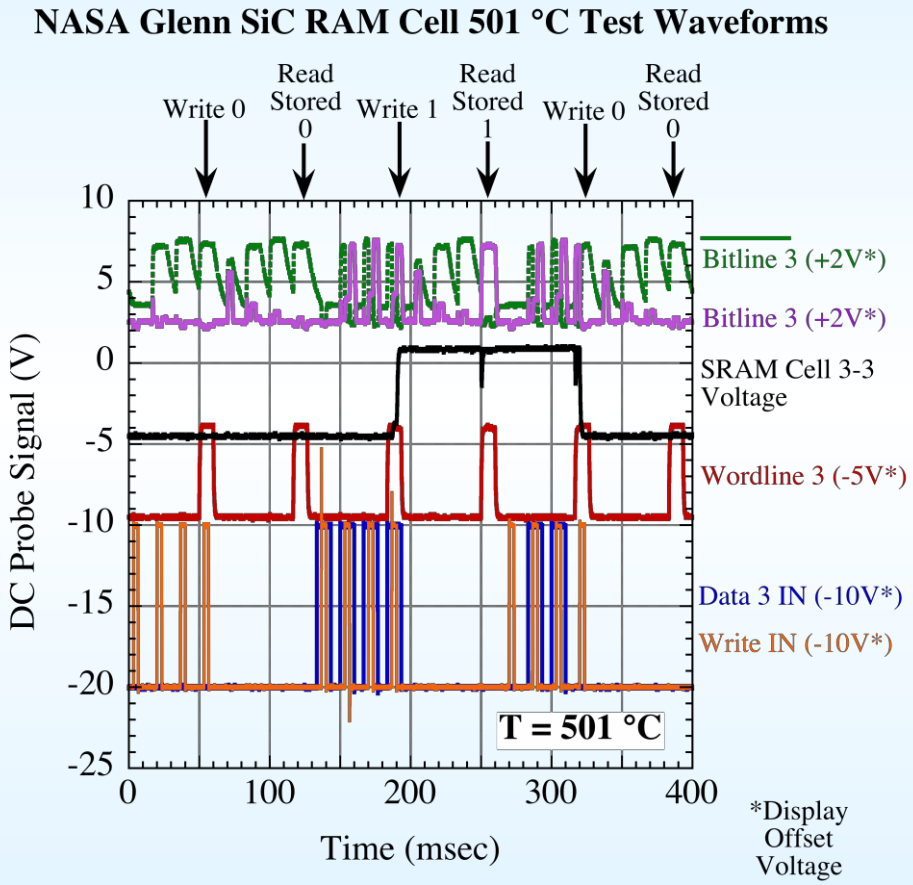


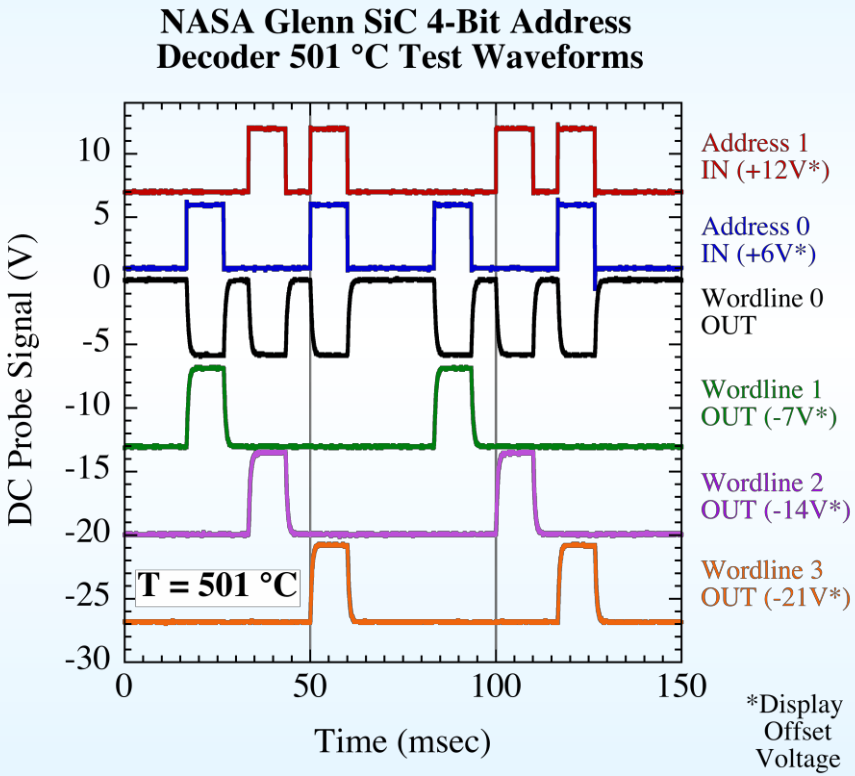


4 X 4-Bit Static Random Access Memory (RAM)



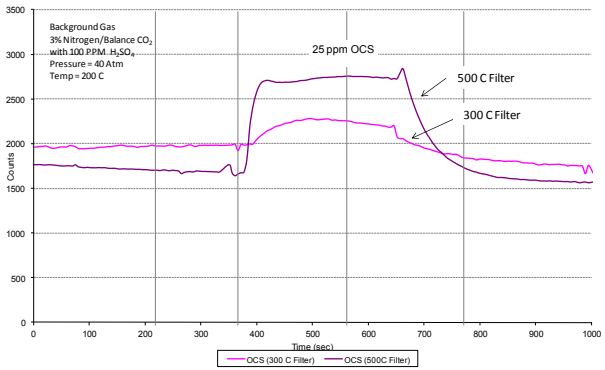
RAM Operation at 500 ºC



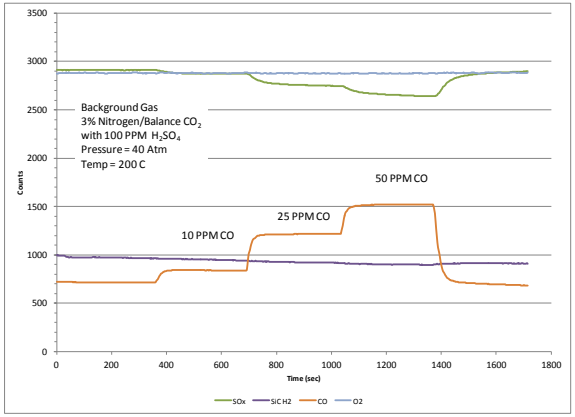


Waveforms demonstrate ability to read and write to select bits at 500 °C

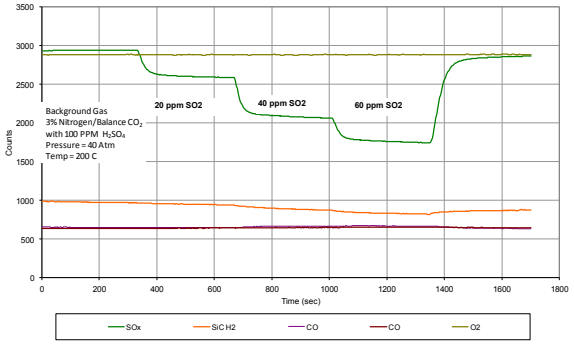
Key Sensing Technologies Have Been Demonstrated in Relevant Conditions



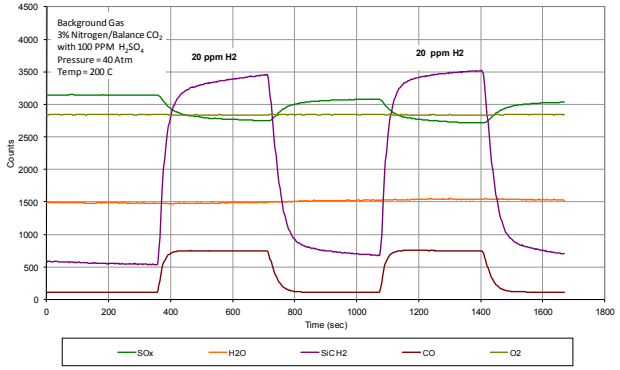
OCS Detection Using Heated Filter



Chemiresistive CO Sensor @ 460 C



Solid Electrolytic SO_2 Sensor



SiC Diode Hydrogen Sensor @ 500 C

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