

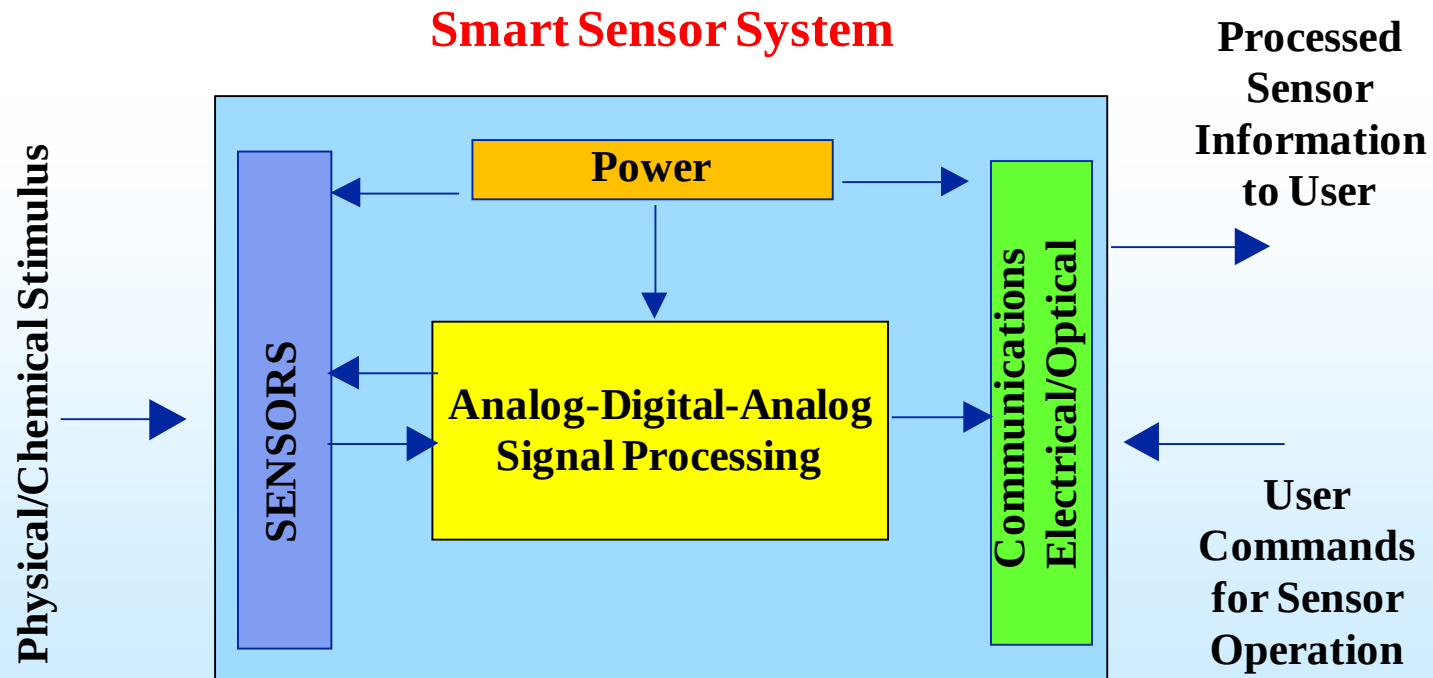
Chemical Sensor Platforms and Systems for Aerospace Applications

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Cleveland, OH



SMART SENSOR SYSTEMS BASED ON MICROSYSTEMS TECHNOLOGY

- A Range Of Sensor Systems Are Under Development Based On Microfabrication Techniques And Smart Sensor Technology
- Smart Sensor Systems Approach: Stand-alone, Complete Systems Including Sensors, Power, Communication, Signal Processing, And Actuation
- Microsystems Technology Moving Towards A Range Of Applications
- Enable System Level Intelligence By Driving Capabilities To The Local Level Using Distributed Smart Systems



BASE PLATFORM SENSOR TECHNOLOGY

Integration of Orthogonal MicroSensor Combinations into Small, Rugged Sensor Suites

Example Applications: AEROSPACE VEHICLE FIRE, FUEL LEAKS, EMISSIONS, ENVIRONMENTAL MONITORING, CREW HEALTH, SECURITY

Multi Species Fire Sensors for Aircraft Cargo Bays and Space Applications



Microfabricated Fire Detection Sensors

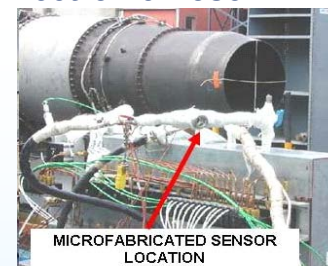
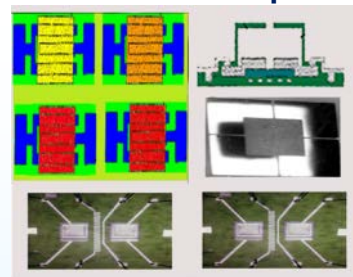
Environmental monitoring (ISS Whitesand Testing)



"Lick and Stick" Space Launch Vehicle Leak Sensors with Power and Telemetry

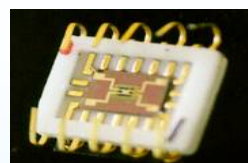


Aircraft Propulsion Exhaust High Temperature Electronic Nose



MICROFABRICATED SENSOR LOCATION

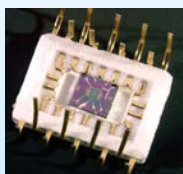
MAKEL
ENGINEERING



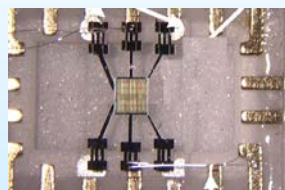
Oxygen Sensor



SiC Hydrocarbon Sensor



H2 Sensor



Nanocrystalline Tin Oxide NOx and CO Sensor

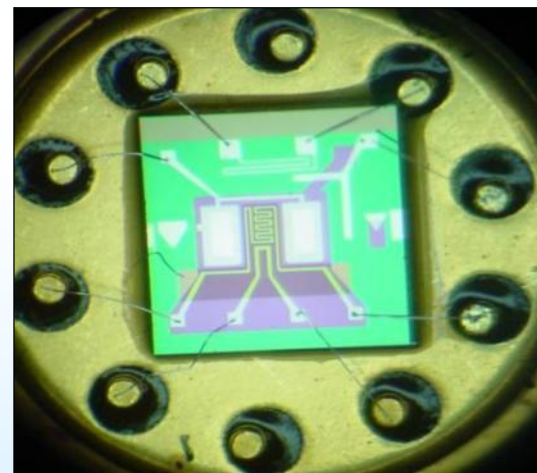
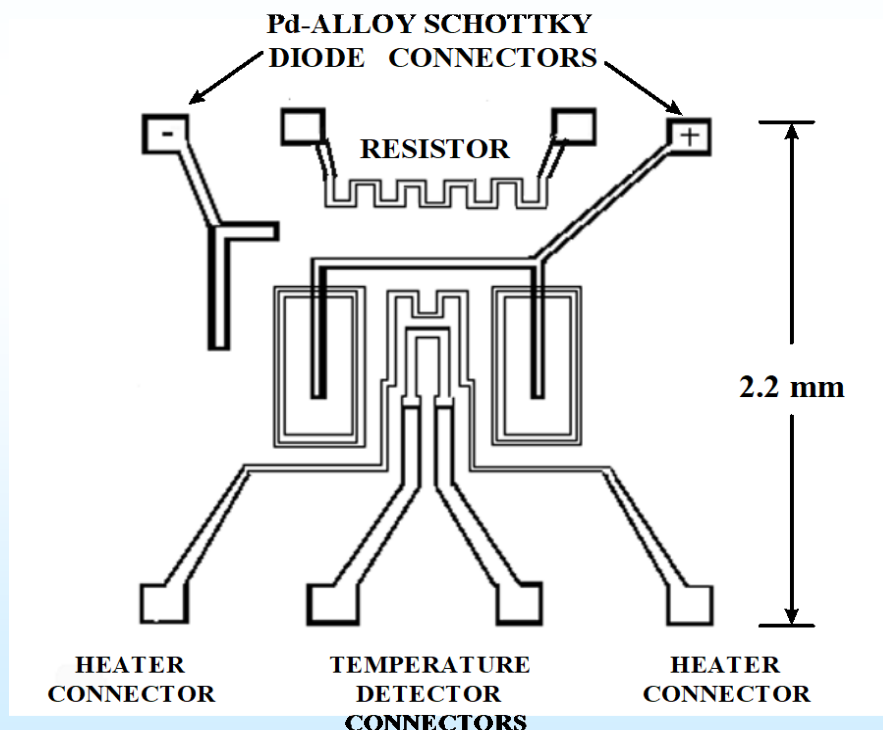


Breath Sensor System Including Mouthpiece, PDA Interface, And Mini Sampling Pump

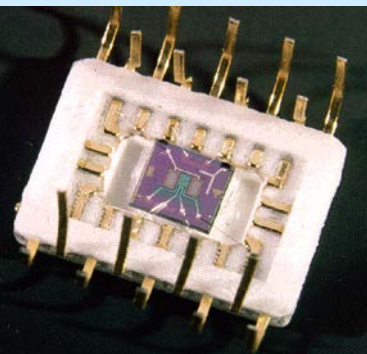
Hydrazine EVA Sensors (ppb Level Detection)

HYDROGEN LEAK SENSOR TECHNOLOGY

- Microfabricated Using MEMS-based Technology For Minimal Size, Weight And Power Consumption
- Designed To Operate Without Oxygen And In Vacuum Environments
- Highly Sensitive In Inert Or Oxygen-bearing Environments, Wide Concentration Range Detection
- Two Sensor System For Full Range Detection: From ppm Levels To 100%



HYDROGEN LEAK SENSOR TECHNOLOGY



- STATUS: OPERATIONAL SYSTEM ON ISS WITH ASSOCIATED HARDWARE
- AVAILABLE FOR POSSIBLE LAUNCH VEHICLE IMPLEMENTATION

R&D 100 AWARD WINNER

NASA TURNING GOALS INTO REALITY SAFETY AWARD

Shuttle



X33



X43



Helios



ISS



Aft Compartment
Hydrogen Monitoring



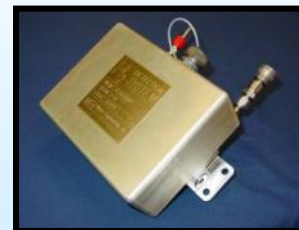
Hydrogen Safety
Monitoring



Hydrogen Safety
Monitoring



Fuel Cell Safety and
Process Monitoring

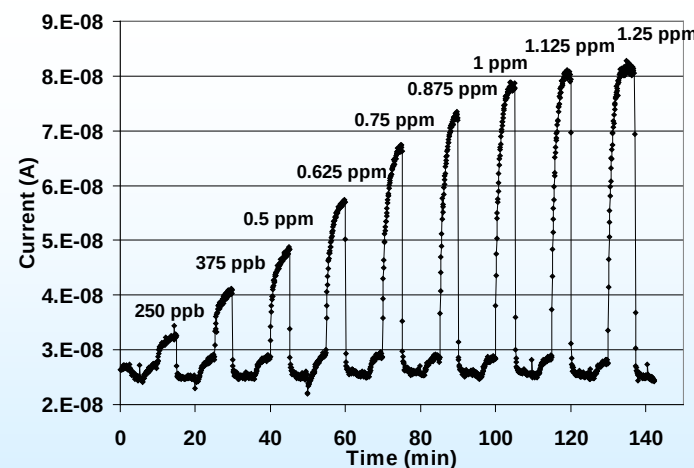


Life Support Process
and Safety Monitoring

SiC-BASED GAS SENSOR DEVELOPMENT

- The Use Of SiC Semiconductors Allows Operation At A Range Of Temperatures For Detection Of Hydrocarbons And NO_x
- Selection of Sensing Alloy, Operating Temperature, and Filtering Can Allow Detection of a Range of Species
- Schottky Diode Design For High Sensitivity
- Wide Range Of Applications
 - Emissions Monitoring
 - Engine Health Monitoring
 - Hydrocarbon Fuel Leak Detection
 - Fire Safety and Environmental Monitoring
- Sensors Tested In Range of Environments including Engines
- **Nominated Twice for NASA Invention Of The Year**

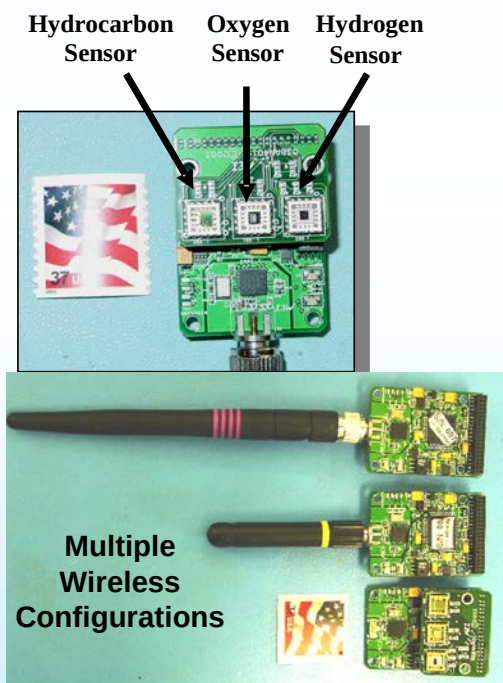
PACKAGED SiC-BASED SENSOR



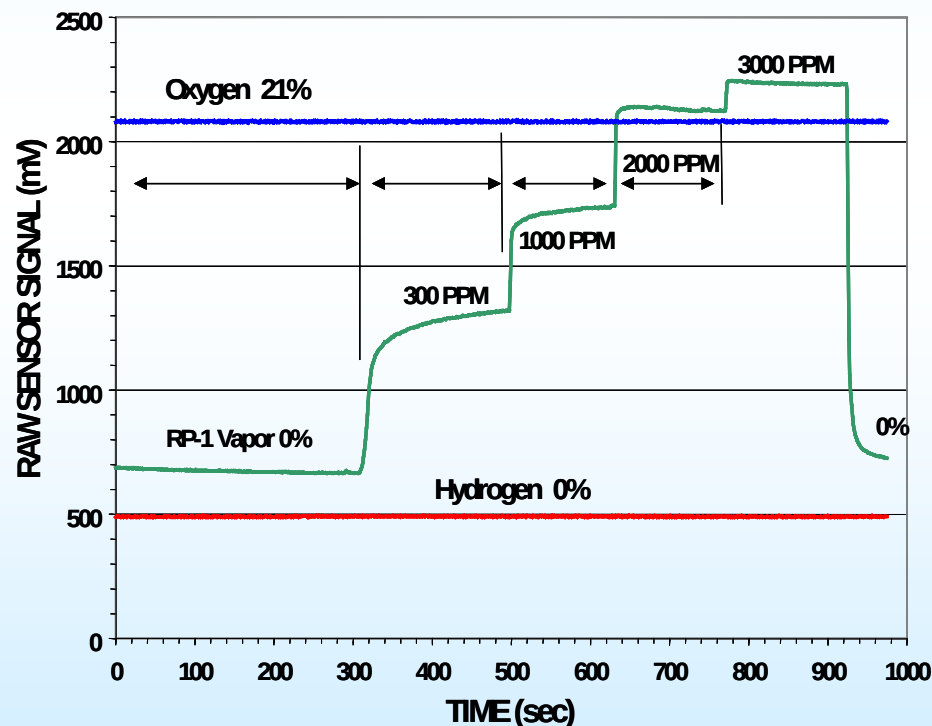
OUTPUT CURRENT OF Pd/PdO_x/SiC
SENSOR TO HYDROGEN BIASED AT 0.45 V
AT 180°C

“LICK AND STICK” SENSOR SYSTEM

- SENSORS, POWER, AND TELEMETRY SELF-CONTAINED IN A SYSTEM NEAR THE SURFACE AREA OF A POSTAGE STAMP
- MICROPROCESSOR INCLUDED/SMART SENSOR SYSTEM
- ADAPTABLE CORE SYSTEM WHICH CAN BE USED IN A RANGE OF APPLICATIONS
- MULTIPLE CONFIGURATIONS AVAILABLE, INCLUDING BATTERY OR CONNECTED POWER
- IN-FLIGHT AND GROUND OPERATION APPLICATIONS



Wireless Data
Transmission/
Orthogonal
Detection

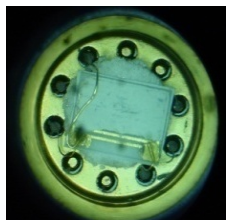


BASIC APPROACH: MEET THE NEEDS OF MULTIPLE APPLICATIONS BUILDING FROM A CORE SET OF SMART MICROSENSOR TECHNOLOGY

Engine Emissions Monitoring System Approach

Target Analyte Detection	Sensor Type	Nominal Range	Selectivity
CO	Resistor	0-5000 PPM	High, but sensitive to low O ₂ concentrations
CO ₂	Electrochemical cell	0.3-4%	High
O ₂	Electrochemical cell	10-21%	High
Hydrocarbons	Schottky diode	0-200 PPM	High
NO _x	Electrochemical cell	0-100 PPM	High, with integration of a high temperature filter

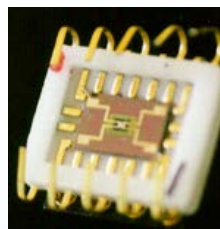
Overview Of Sensor Element Properties



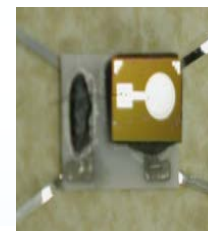
Titanium oxide-based CO sensor



Lithium phosphate based CO₂ sensor



Zirconia based O₂ sensor



Silicon carbide based hydrocarbon sensor

Representative Pictures Of Sensor Elements

Sensor element mounted in custom A/N fitting



Assembled probe with lead wire connections



Sensor probe assemblies mounted in a flow-through manifold



Engine Emission Probe Assembly

Emissions Sensor Suite Volcanic Ash Testing

OBJECTIVE

- Demonstrate the ability to diagnose engine faults and performance loss effects using a multiparameter emission sensor array

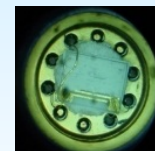
APPROACH

- Engine Emission Monitoring System developed using selective microsensors and smart electronics
- Includes the capability to measure CO, CO₂, O₂, hydrocarbons, and NO_x.
- Sensor suite mounted at engine exhaust and exposed to both nominal conditions and simulated faults, as well as volcanic ash

RESULTS AND SIGNIFICANCE

- (Preliminary/Volcanic Ash)
- Emissions Sensor Array Monitored Engine Emissions during Days 1-3, 5 of Ash runs
- Days 1-3: Candidate “Steady-State” Emissions Parameter Identified
- Day 5 Deviation in “Steady State” Emissions Profile Suggestive of Change in Engine State During Heavy Volcanic Ash Deposition
 - Not Presently Explainable By Reference to Other Engine Parameters

Multiparameter Engine Exhaust Measurements Track Major Species



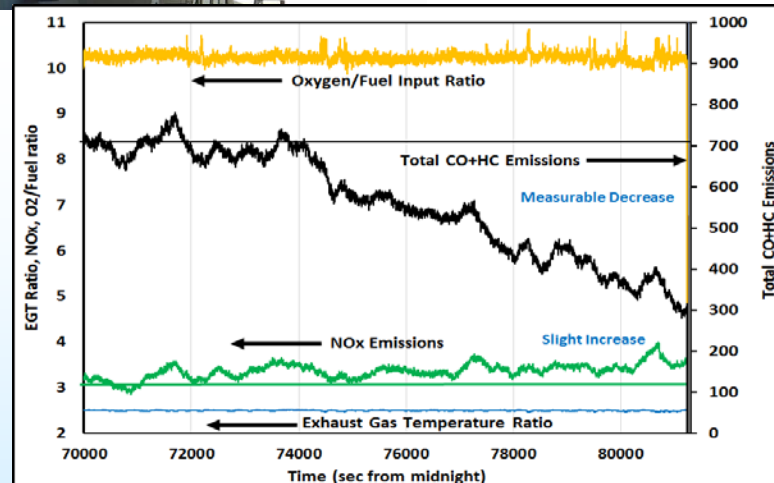
CO
sensor



Sensor probe



Sensor
probes in
emissions
testing rig
manifold

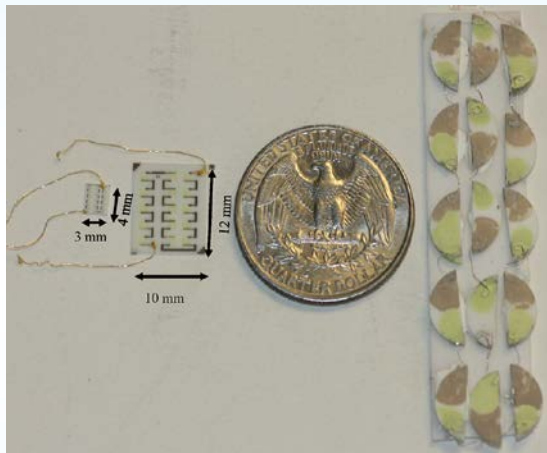


Preliminary Emissions Data –

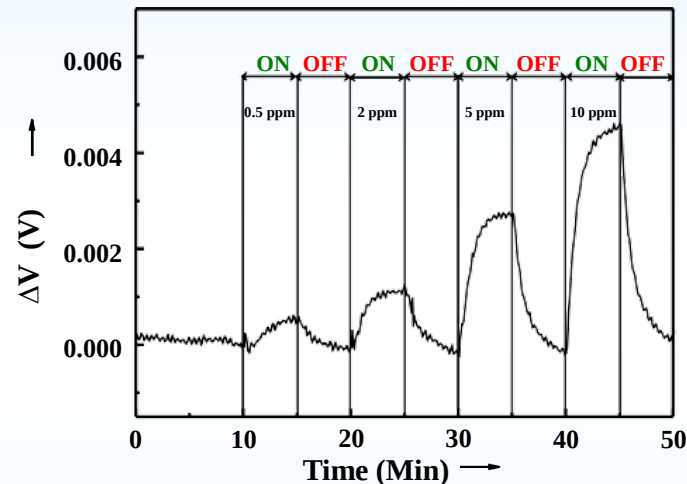
- Pattern Established Over Several Runs
- Deviations from Baseline Observed Suggesting Possible Volcanic Ash Effects

EXHALED NO ANALYSIS USING ELECTROCHEMICAL SENSOR MINIATURIZATION EXAMPLE

- Nitric Oxide Sensor Core To Portable Asthma Monitoring Approach
- Sensor Miniaturization Using Silicon Processing Techniques
- Electrochemical Cells In Series To Reach High Levels Of Sensitivity (500 ppb) With More Than An Order Of Magnitude Size Reduction
- Fundamental Understanding Of Sensing Mechanism Needed



Miniaturization Activity: Hand fabricated sensor (baseline), shadow mask sensor, and photoresist processed sensor

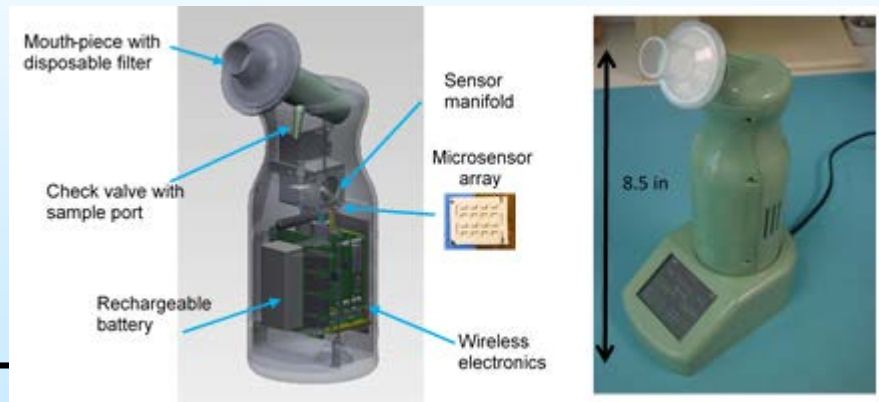


Sensor response of photoresist version sensor with 15 sensor arrays for 0.5–10 ppm in 20% O₂ with 200 cm³/min total flow rate at 550°C

MAKEL
ENGINEERING



The core components for a notional home use portable breath monitor, and mounting in a charging unit with a display.



High Temperature Micro Sensors for Venus Atmospheric Measurements

- Small, compact multi-species sensor orthogonal array when combined with SiC electronics which requires no cooling

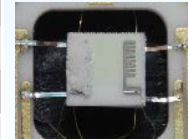
Species	Technology	Operating Temp	Range	Status
CO	TiO ₂	500 C	0-50 PPM	Prototype tested*
OCS	TiO ₂ sensor with Fe filter	500 C	0-50 PPM	Prototype tested*
SO _x	Solid ion electrolytes	500 C	0-400 PPM	Prototype tested*
H ₂ O	Differential Bias ZrO ₂	500 C	0-100 PPM	Prototype tested*
HF	SiC Diode and LaF chem resistor	500 C	0-5 PPM	Prototype tested*
HCl	Solid electrolyte	500 C	0-5 PPM	Prototype tested*
NO	Pt-Zeolite and WO ₃ on YSZ	500 C	0-10 PPB	Prototype tested*
O ₂	Amperometric ZrO ₂	500 C	0-50 PPB	Prototype tested*
H ₂	SiC Diode	500 C	0-1 PPB	Prototype tested*



OCS



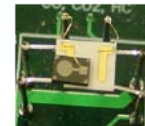
CO



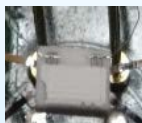
HCl



NO



HC

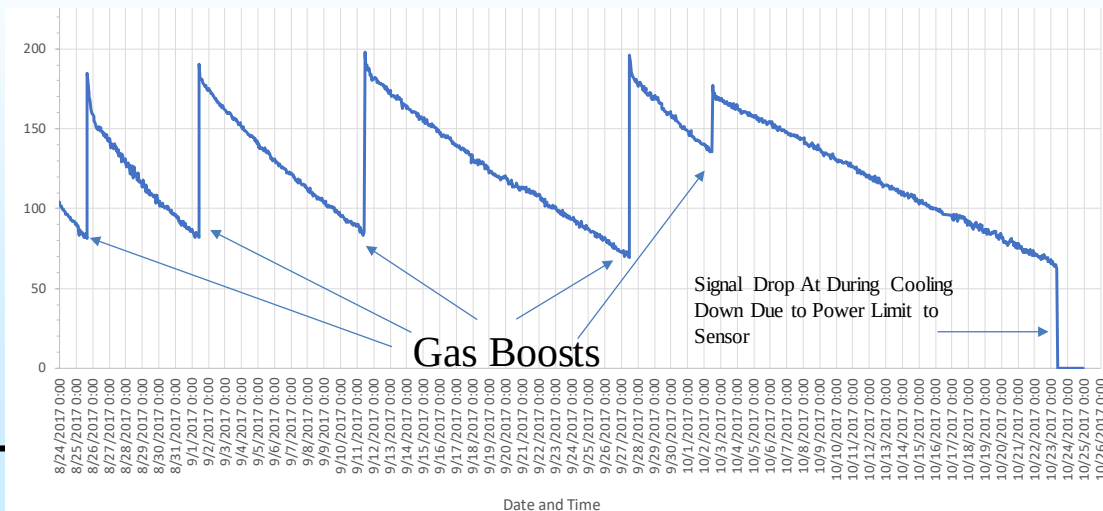
SO_xO₂

HF

H₂O

***Successfully Demonstrated in Lab Testing At High Pressure With Simulated Venus Atmosphere Gas Mixtures**

SO_x Sensor During 60 Day Venus Simulated Surface Testing



Micro-Fabricated Gas Sensors for Fire Detection and Environmental Monitoring

- Enhanced Environmental/Hazard Monitoring With Multiparameter Approach
- Demonstrated Reduction Of Fire False Alarms In Aircraft Cargo Bay With Improved Understanding Of The Environment
 - FAA Cargo Bay Simulation Testing: *No False Alarms/Consistent Detection Of Fires*
- Environmental Monitoring and Fire Detection; Dual Use System Targeting Key Species Of Interest To Human Health In Multiple Configurations
- First Responder Applications On-going: Portable Monitor For Exposure To Hazardous Species And Improved Situational Awareness



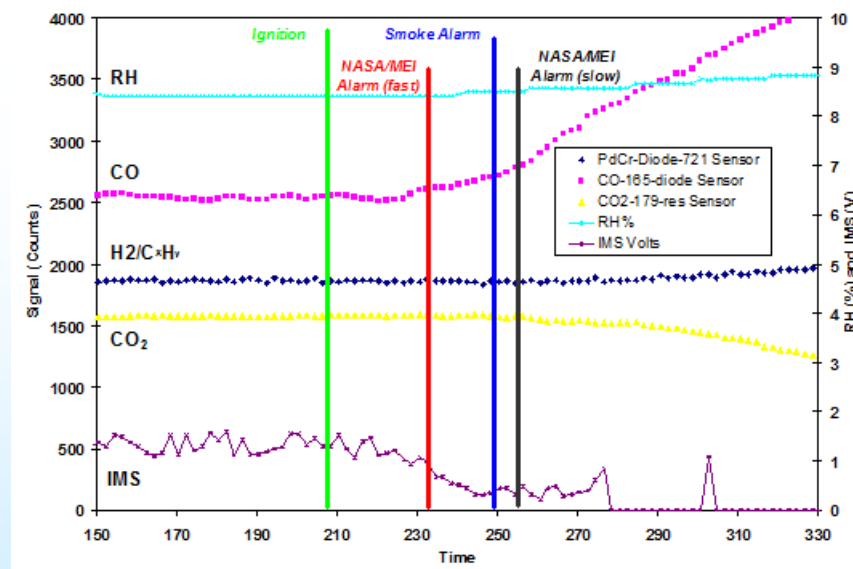
SMART SPACE FIRE
DETECTION SYSTEM



HAND HELD UNIT



WIRELESS MODULE



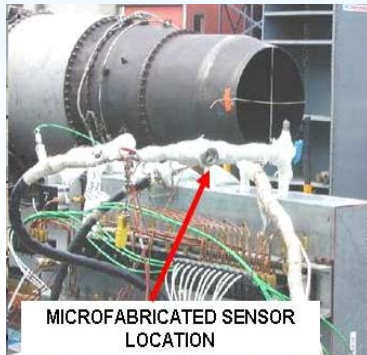
AIRCRAFT
CARGO BAY
FIRE
DETECTION

R&D 100 AWARD WINNER

TURNING GOALS INTO REALITY AA's CHOICE AWARD

A WIDE RANGE OF SYSTEM DEMONSTRATIONS AND APPLICATIONS “LICK AND STICK” CORE HARDWARE

**Jet Engines
Emissions**



**Aircraft Fire
Detection**



Breath Monitoring



**NASA Helios
Fuel Cells**



**International Space
Station Safety System**



**Rocket Engine
Teststands**



**Environmental
Monitoring**

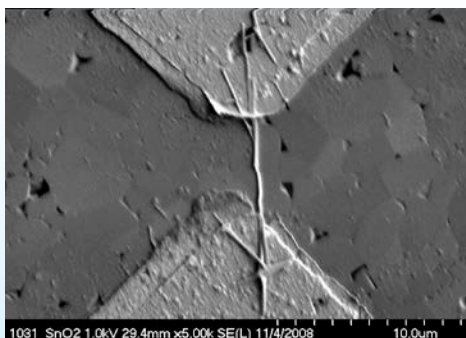
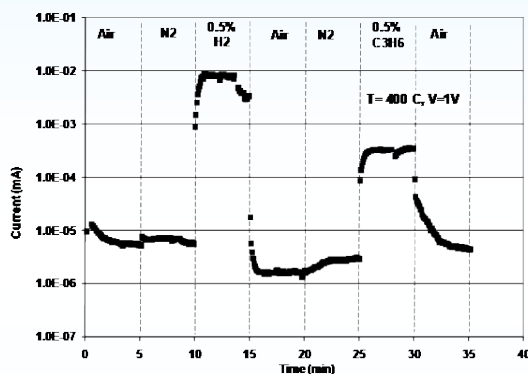


**Cryogenic Fuel
Line Monitoring**

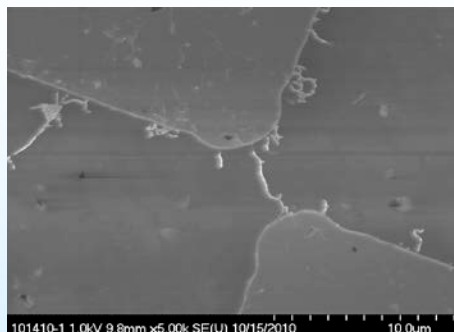
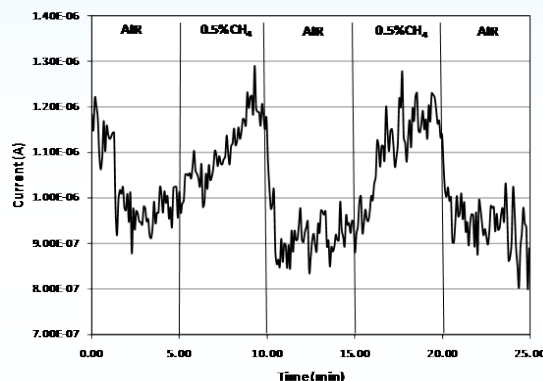


Microfabrication Techniques Applied To Nanotechnology

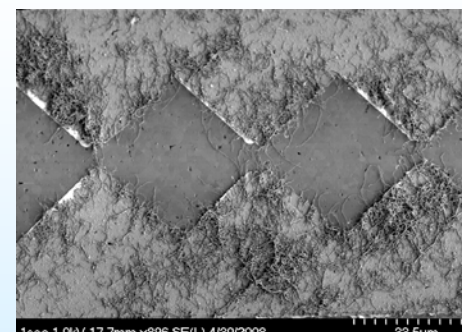
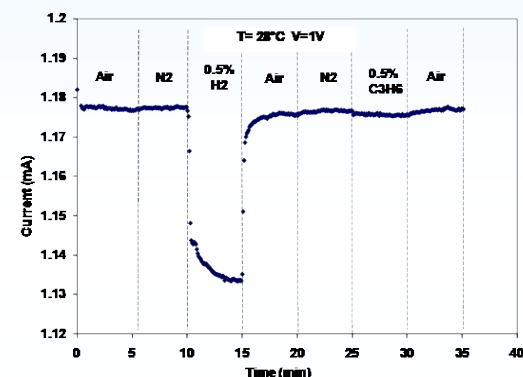
- Integration of standard microfabrication techniques with the alignment of nanostructures
- Length of nanostructures are affected by AC frequency used for alignment
- Core of the approach is to Mix Nanomaterials into the Photoresist Standardly Used for Microfabrication, Followed By Dielectrophoresis for Alignments
- Implies Nanostructures Can Be Integrated into Standard Microfabrication Processing At Multiple Stages in Sensor/Device Processing



Tin Oxide Operational at 400°C
Measuring Hydrogen and
Hydrocarbons



**Templated Tin Oxide Measuring
Methane at Room Temperature**
New capability

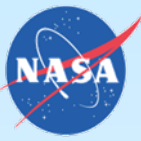


**Carbon Nanotubes Operational
at Room Temperature**



SUMMARY

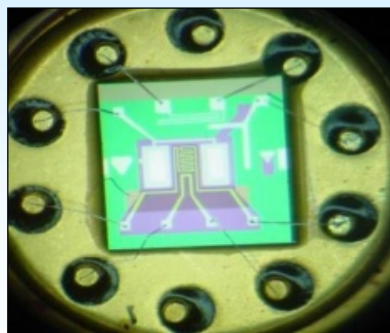
- **Revolutionary Changes in a Range Of Applications can be Enabled By Smart Micro/Nano Systems**
- **Multiuse Micro/Nano Sensor Technology Combined With A Basic Hardware Platform (e.g., “Lick And Stick” Technology) Enabling Smart Chemical Sensor Systems**
 - **Includes Processing, Power, and Communications as Appropriate for the Application**
 - **Local Processing to Optimize Data Stream Provided**
- **Orthogonal, Multiparameter, Resilient Sensors Core to the Approach**
 - **Core Platform Technology Tailored for a Range of Species Measurements**
 - **A Broad Range of Selective Sensors Yield Quantitative Data**
- **A Range Of Chemical Sensor Systems Developed and Applied**
 - **Smart Core Adapted To Applications from a Jet Engine to a Cryofluid Line**
 - **Sensor System Configuration (Sensors, Hardware, Interfaces) Tailored for Application**
- **Nanotechnology Based Sensors Developed Using Microfabrication Processing Technology**
- **Do Something With The Data: Diagnosis Combined With Mitigation**



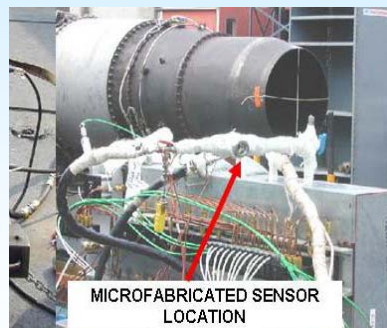
Backup Slides

Chemical Gas Species Sensors

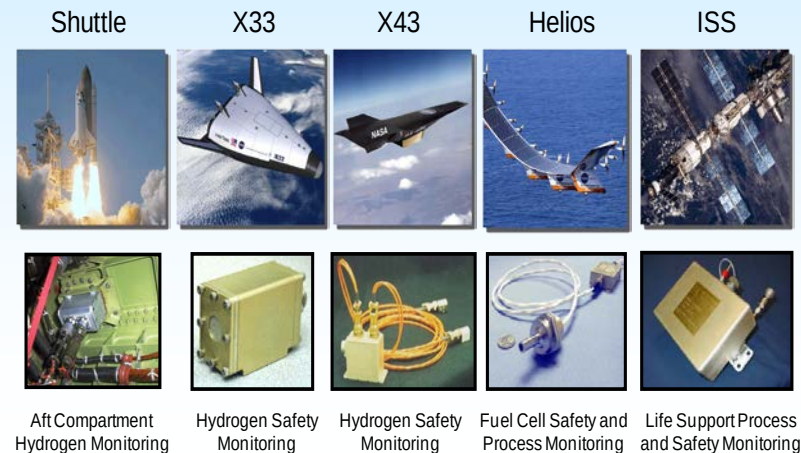
Leak detection, emission, fire and environmental, and human health monitoring



Hydrogen Sensor



Emission Monitoring

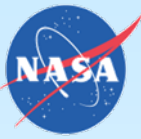


Description of Technology

- Many aerospace sensors are simple single parameter measurement systems limiting adaptability/ data quality.
- This work provides an adaptable Smart Sensor System (with microprocessor): three sensors each providing unique data.
- Enable easy integration into different application environments without the need for mandatory changes in power and communication infrastructure.
- Multiple sensors available depending on application need: hydrogen, oxygen, hydrocarbons, carbon dioxide, and carbon monoxide.

Applications:

- Basic Approach: Building from a core set of smart microsensor technologies, sensor(s) and hardware configuration can be modified to meet the needs of specific applications.
- Leak detection measuring both fuel (hydrogen and hydrocarbons) and oxygen levels to determine hazardous conditions.
- Toxic gas or fuel monitoring.
- Environmental and safety monitoring to detect levels of oxygen, carbon monoxide, and carbon dioxide.



NANO DIMENSIONAL CONTROL PREVALENT IN CHEM/BIO SENSOR DEVELOPMENT

- NANO CONTROL OF CHEMICAL SENSOR STRUCTURES STRONGLY PREFERRED EVEN IF SENSOR ISN'T LABELED A "NANO SENSOR"
 - WE ARE MEASURING VARYING NUMBERS OF MOLECULES
- IF NANOTECHNOLOGY ALREADY PRESENT IN CHEM/BIO SENSOR DEVELOPMENT, THEN:
 - WHAT STAYS THE SAME AND WHAT'S NEW?
 - WHAT ARE THE CHALLENGES IN NANOTECHNOLOGY DEVELOPMENT?
 - WHAT IS THE ROLE/ADVANTAGE OF NANO TECHNOLOGY

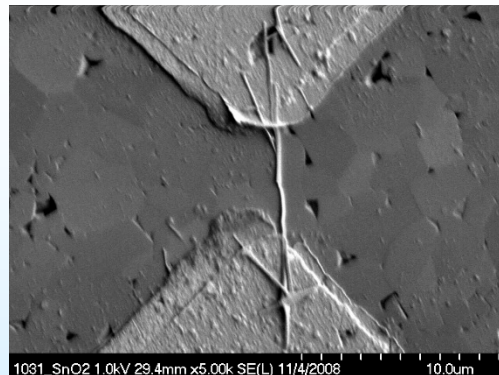
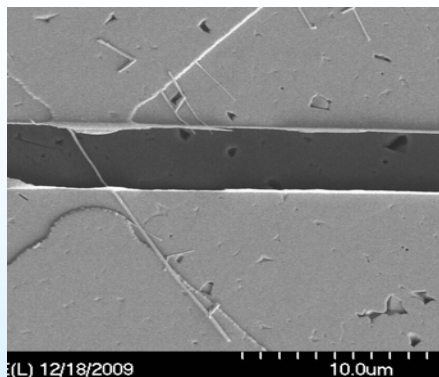
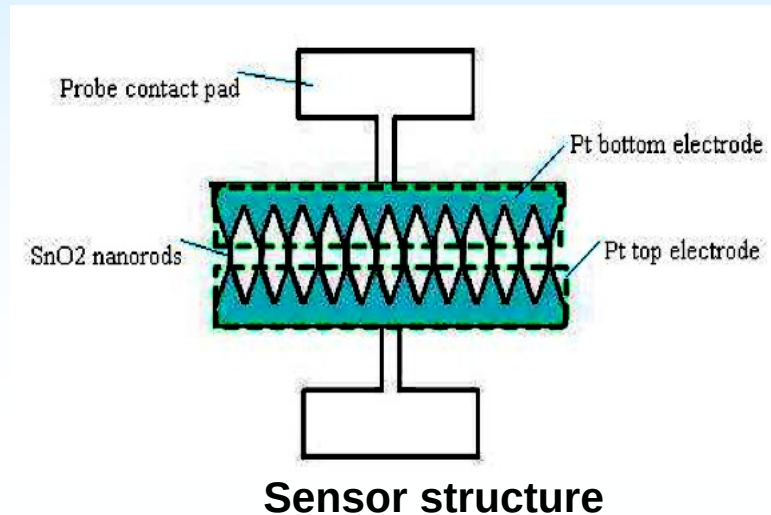
SAME

- APPLICATIONS DON'T CARE THAT IS NANO, NEED IMPROVED CAPABILITIES
- STANDARD SENSOR TECHNOLOGY REQUIREMENTS, POTENTIAL, AND DIRECTIONS SET BY THE ADVENT OF MICRITECHNOLOGY REMAIN CONSTANT
- SENSITIVITY, SELECTIVITY, STABILITY, RESPONSE TIME, TAILOR FOR THE APPLICATION, "LICK AND STICK", ETC.
- PACKAGING STILL SIGNIFICANT COMPONENT OF SYSTEM
- AS WITH MICRO, CAN ONLY GO AS FAR AS THE SUPPORTING TECHNOLOGIES
- MULTIPLE SENSOR PLATFORMS MAY STILL BE NECESSARY DEPENDING ON THE APPLICATION/ENVIRONMENT

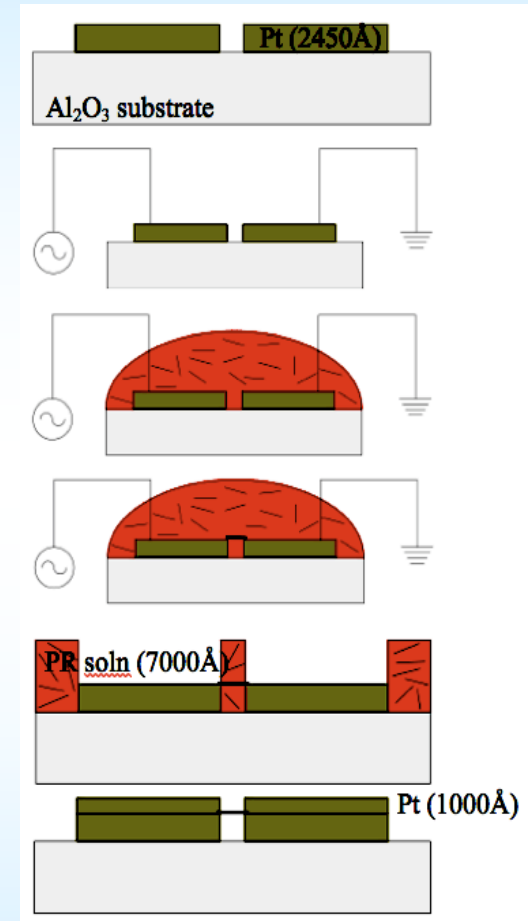
OBJECTIVE: ENABLE FULL IMPLEMENTATION OF "LICK AND STICK" TECHNOLOGY

Micro-Nano Contacts

Microfabrication applied to Nanotechnology (Patented)



Aligned nanostructures with buried contacts



Processing approach