CHEMICAL SENSORS FOR AEROSPACE APPLICATIONS

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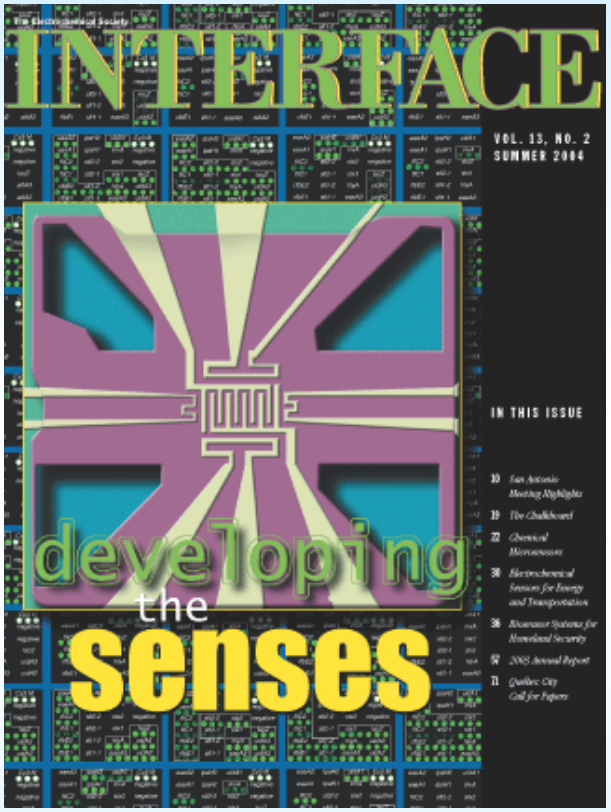
OUTLINE

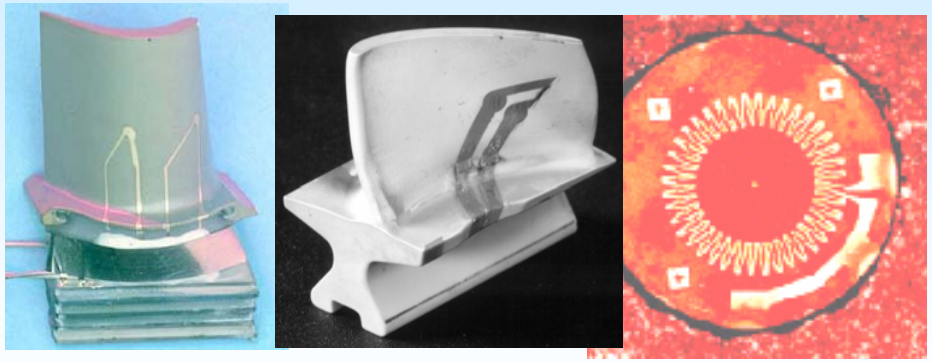
- INTRODUCTION
- MICROFABRICATED GAS SENSORS
- SENSOR DEVELOPMENT
    - HYDROGEN
    - CARBON MONOXIDE AND NITROGEN OXIDES
    - HYDROCARBONS
    - OXYGEN
- LEAK DETECTION
- HIGH TEMPERATURE ELECTRONIC NOSE
- FIRE DETECTION
- SUMMARY AND FUTURE PLANS



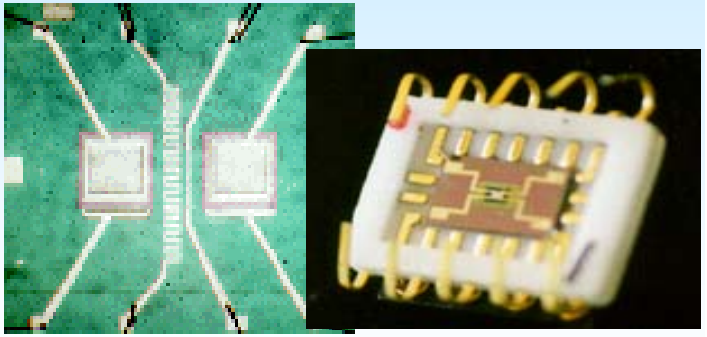
NASA GRC/CWRU O2 Sensor Featured On the Cover of the Electrochemical Society Interface Magazine

SENSORS AND ELECTRONICS TECHNOLOGY BRANCH

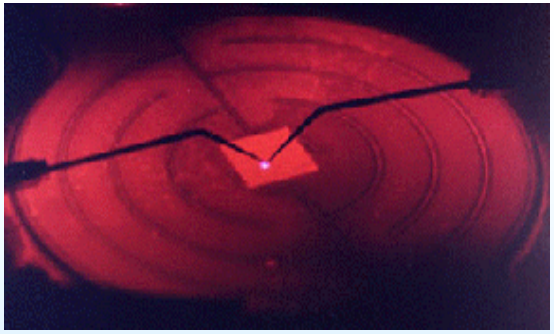
SCOPE OF WORK



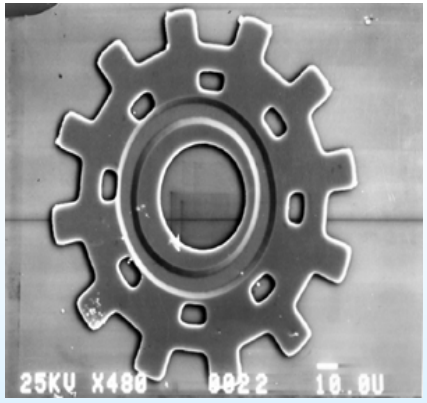
PHYSICAL SENSORS (T, Strain, Heat Flux)



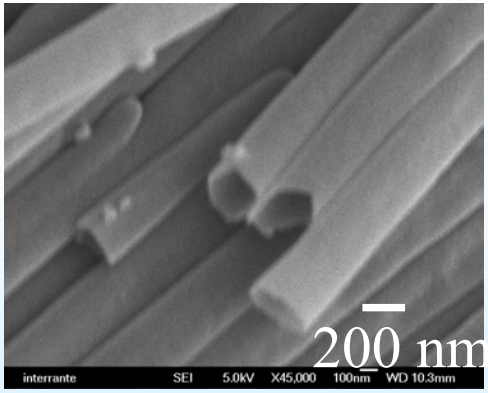
CHEMICAL SENSORS



SILICON CARBIDE HIGH TEMP ELECTRONICS



MICRO-ELECTRO-MECHANICAL SYSTEMS



NANOTECHNOLOGY


SENSORS
THE JOURNAL OF APPLIED SENSING TECHNOLOGY
Tap the Power of the Internet to Monitor Remote Sites
ENHANCING DA
with Intelligent Oversampling
Keeping the Photosensor Signal Clean
MACHINE VIBRATION ANALYSIS:
A Predictive Maintenance Tool
NTC THERMISTORS:
Determining the Level of Uncertainty
Measuring 0.0% Consistency in the Pulp and Paper Industry
The Engineered Cable Assembly
COVER: Researchers Join Forces to Boost Gas Turbine Engine R&D

MICROFABRICATED GAS SENSORS

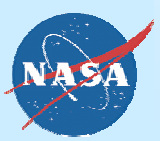
- COLLABORATIVE EFFORT BETWEEN NASA GRC, CASE WESTERN RESERVE, and OHIO STATE UNIVERSITY

- SENSOR DEVELOPMENT RESULTING FROM:
  - IMPROVEMENTS IN MICROFABRICATION AND MICROMACHINING TECHNOLOGY
  - NANOMATERIALS
  - DEVELOPMENT OF SiC-BASED SEMICONDUCTOR TECHNOLOGY

- GAS DETECTION IN:
  - HARSH ENVIRONMENTS
  - APPLICATIONS BEYOND CAPABILITIES OF COMMERCIAL SENSORS

- TECHNOLOGY DEVELOPS PLATFORMS FOR A VARIETY OF MEASUREMENTS
  - SCHOTTKY DIODE
  - RESISTANCE BASED
  - ELECTROCHEMICAL

- TARGET DETECTION OF GASES OF FUNDAMENTAL INTEREST
  - HYDROGEN (H_2)
  - HYDROCARBONS (C_xH_y)
  - NITROGEN OXIDES (NO_X) AND CARBON MONOXIDE (CO)
  - OXYGEN (O_2)
  - CARBON DIOXIDE (CO_2)



CHEMICAL SENSOR APPLICATION DEVELOPMENT AREAS

SAFETY

LEAK DETECTION

DETECTION OF FUEL AND OXYGEN LEAKS FOR SPACE TRANSPORTATION APPLICATIONS SUCH AS SPACE SHUTTLE, X-43 AND NEXT GENERATION LAUNCH TECHNOLOGY. WIDE RANGE DETECTION IN INERT ENVIRONMENTS AND POSSIBLY CRYOGENIC CONDITIONS.

FIRE DETECTION

DETECTION OF FIRE PRECURSORS (E.G. CO AND CO2) IN CARGOBAY APPLICATIONS TO SUPPLEMENT EXISTING TECHNOLOGY. CHEMICAL SIGNATURE IN THE PRESENCE OF A NUMBER OF INTERFERING GASES. COMPLEMENT EXISTING SMOKE DETECTION SYSTEMS.

EMISSIONS

DETECTION OF HYDROCARBONS, NOx, CO, ETC. FOR HEALTH MONITORING AND ACTIVE COMBUSTION CONTROL APPLICATIONS. SENSITIVE DETECTION IN HIGH TEMPERATURE HARSH ENVIRONMENTS IN THE PRESENCE OF A NUMBER OF INTERFERING GASES.

ENVIRONMENTAL MONITORING/BIO

DETECTION OF HYDRAZINE FOR ISS/EVA APPLICATIONS

DETECTION OF NOx/CO FOR ASTHMA MONITORING

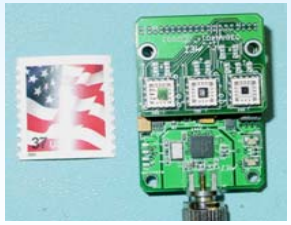
BASE PLATFORM SENSOR TECHNOLOGY

Integration of Micro Sensor Combinations into Small, Rugged Sensor Suites

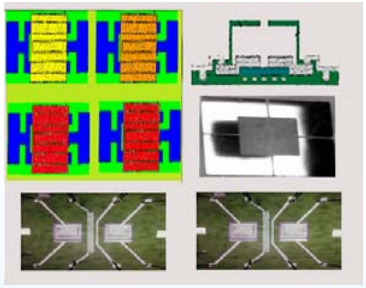
Example Applications: AEROSPACE VEHICLE FIRE, FUEL, EMISSIONS, ENVIRONMENTAL MONITORING CREW HEALTH, SECURITY

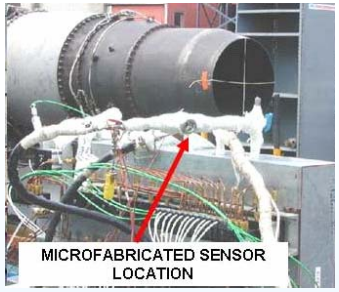
Multi Species Fire Sensors for Aircraft Cargo Bays

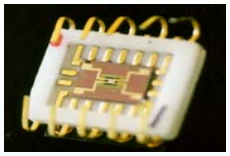
"Lick and Stick" Space Launch Vehicle Leak Sensors with Power and Telemetry



Aircraft Propulsion Exhaust High Temperature Electronic Nose

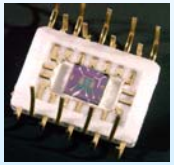




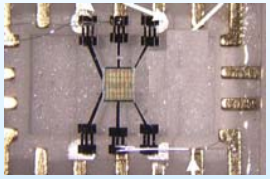


Oxygen Sensor

SiC Hydrocarbon Sensor

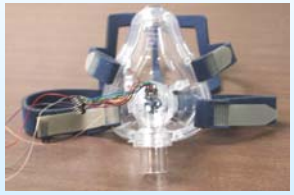


H2 Sensor



Nanocrystalline Tin Oxide NOx and CO Sensor

Hydrazine EVA Sensors (11 ppb Detection)



Sensor Equipped Prototype Medical Pulmonary Monitor

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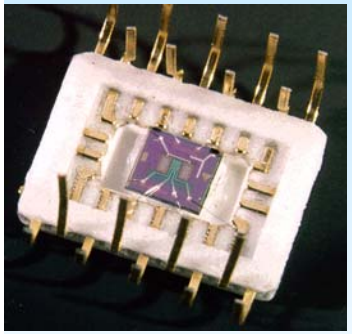
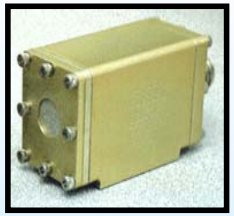
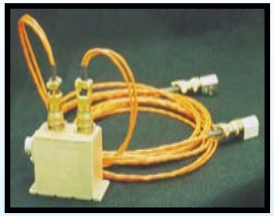
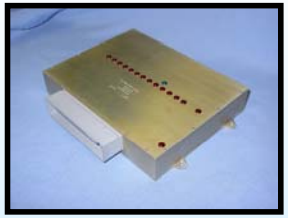
HYDROGEN LEAK SENSOR TECHNOLOGY: MEMS APPLIED IN SPACE AND COMMERCIAL APPLICATIONS



- MICROFABRICATED USING MEMS-BASED TECHNOLOGY FOR MINIMAL SIZE, WEIGHT AND POWER CONSUMPTION
- HIGHLY SENSITIVE IN INERT OR OXYGEN-BEARING ENVIRONMENTS, WIDE CONCENTRATION RANGE DETECTION

1995 R&D 100 AWARD WINNER

NASA 2003 TURNING GOALS INTO REALITY SAFETY AWARD

Shuttle	X33	X43	Helios	IIS	Model U
					
					
Aft Compartment Hydrogen Monitoring	Hydrogen Safety Monitoring	Hydrogen Safety Monitoring	Fuel Cell Safety and Process Monitoring	Life Support Process and Safety Monitoring	Vehicle Safety Monitoring

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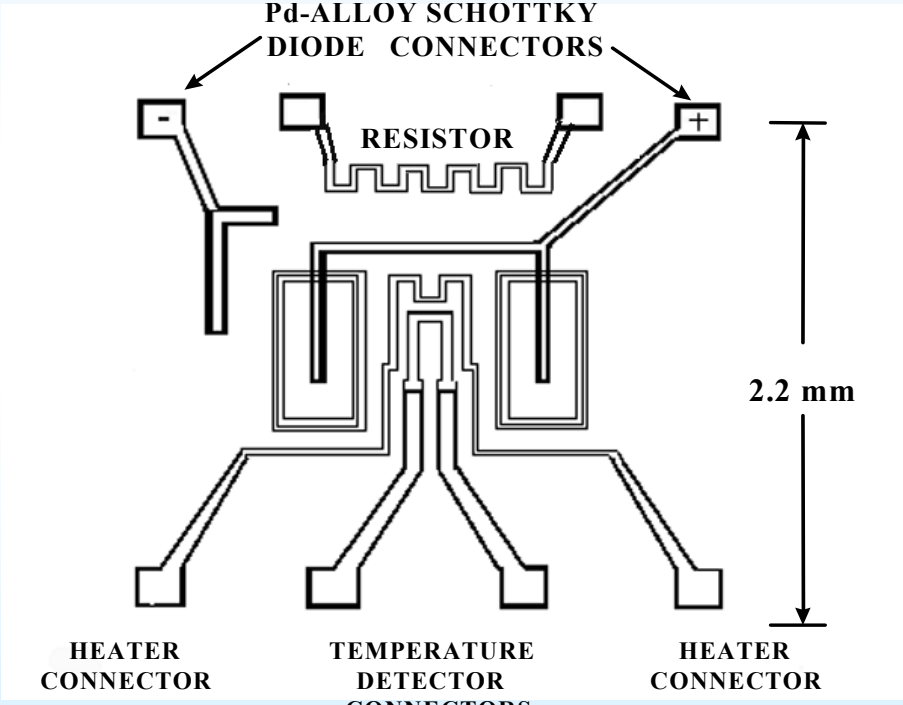
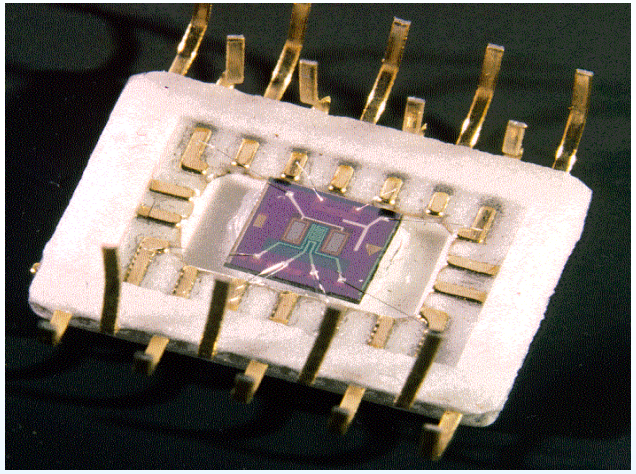
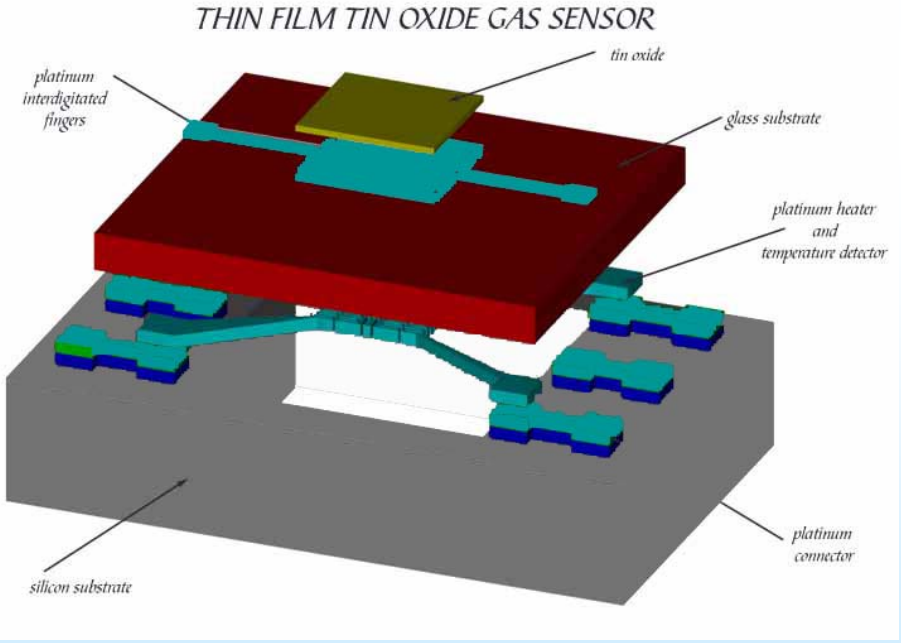
WIDE CONCENTRATION RANGE HYDROGEN SENSOR DESIGN

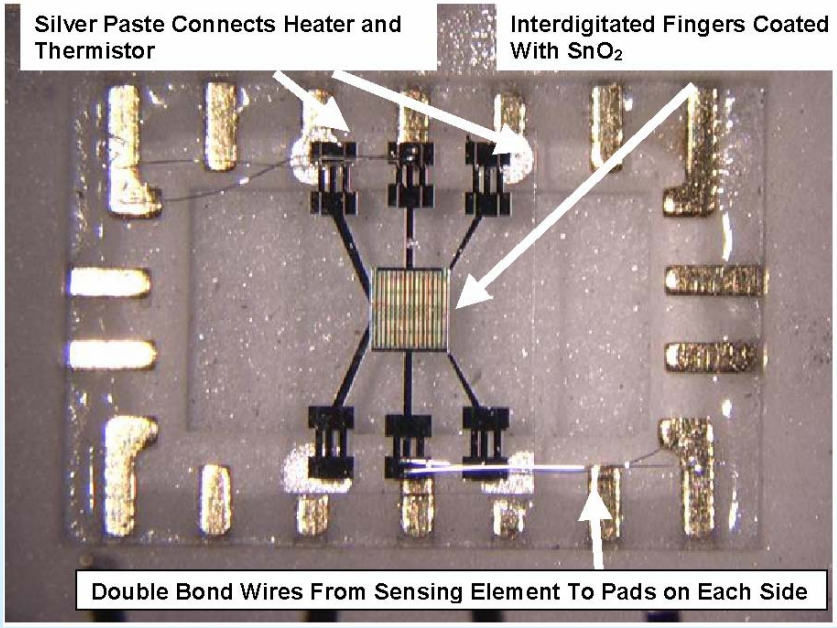




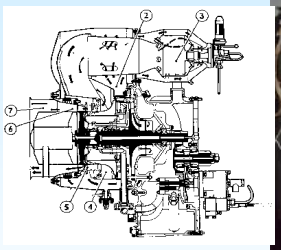
MICROFABRICATED TIN OXIDE BASED NOx AND CO SENSOR TECHNOLOGY

- **MICROFABRICATED FOR MINIMAL SIZE, WEIGHT AND POWER CONSUMPTION**
- **MICROMACHINED TO MINIMIZE POWER CONSUMPTION AND IMPROVE RESPONSE TIME**
- **TEMPERATURE DETECTOR AND HEATER INCORPORATED INTO SENSOR STRUCTURE**
- **NANOFABRICATION OF TIN-OXIDE TO INCREASE SENSOR STABILITY**





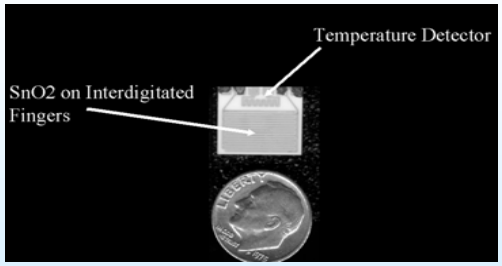
DEMONSTRATION TESTING OF NANOCRYSTALLINE NOx SENSOR IN GAS TURBINE EXHAUST STREAM

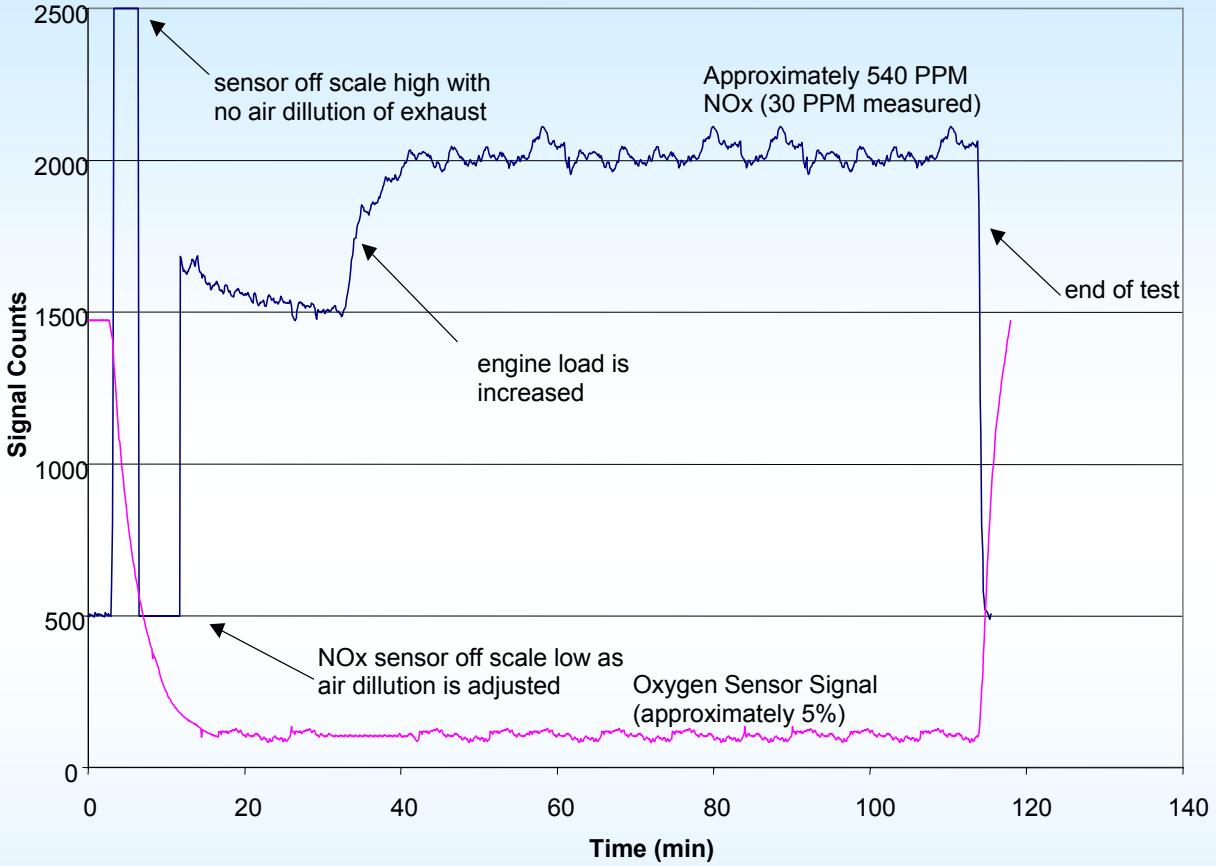


50 Hp Gas Turbine

Industry Standard Continuous Emission Monitoring Equipment

REPLACE INSTRUMENT RACK SIZED SYSTEM WITH DIME SIZED SENSOR AND ACCOMPANYING ELECTRONICS





Species	CEM Measurement	MSES Measurement
NOx	593 PPM	540 PPM
CO	3000 PPM	N/A
O_2	4.57%	5%

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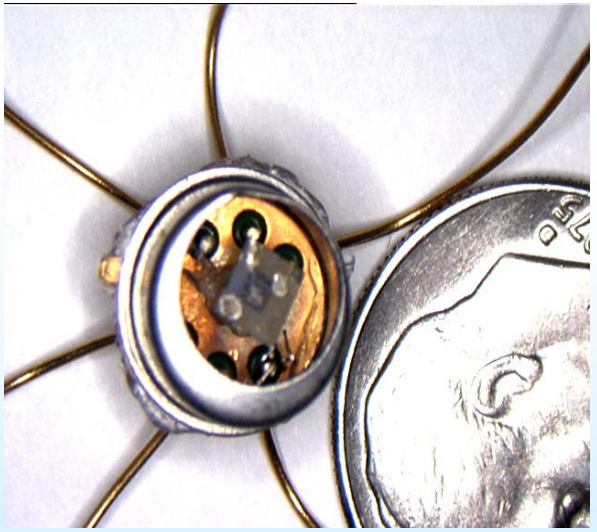
SiC-BASED GAS SENSOR DEVELOPMENT

- THE USE OF SiC SEMICONDUCTORS ALLOWS SENSOR OPERATION AT TEMPERATURES WHICH ALLOW THE DETECTION OF HYDROCARBONS AND NOx
- SCHOTTKY DIODE DESIGN FOR HIGH SENSISTIVITY
- TEMPERATURE DETECTOR AND HEATER INCLUDED

  OPERATION AT A RANGE OF TEMPERATURES

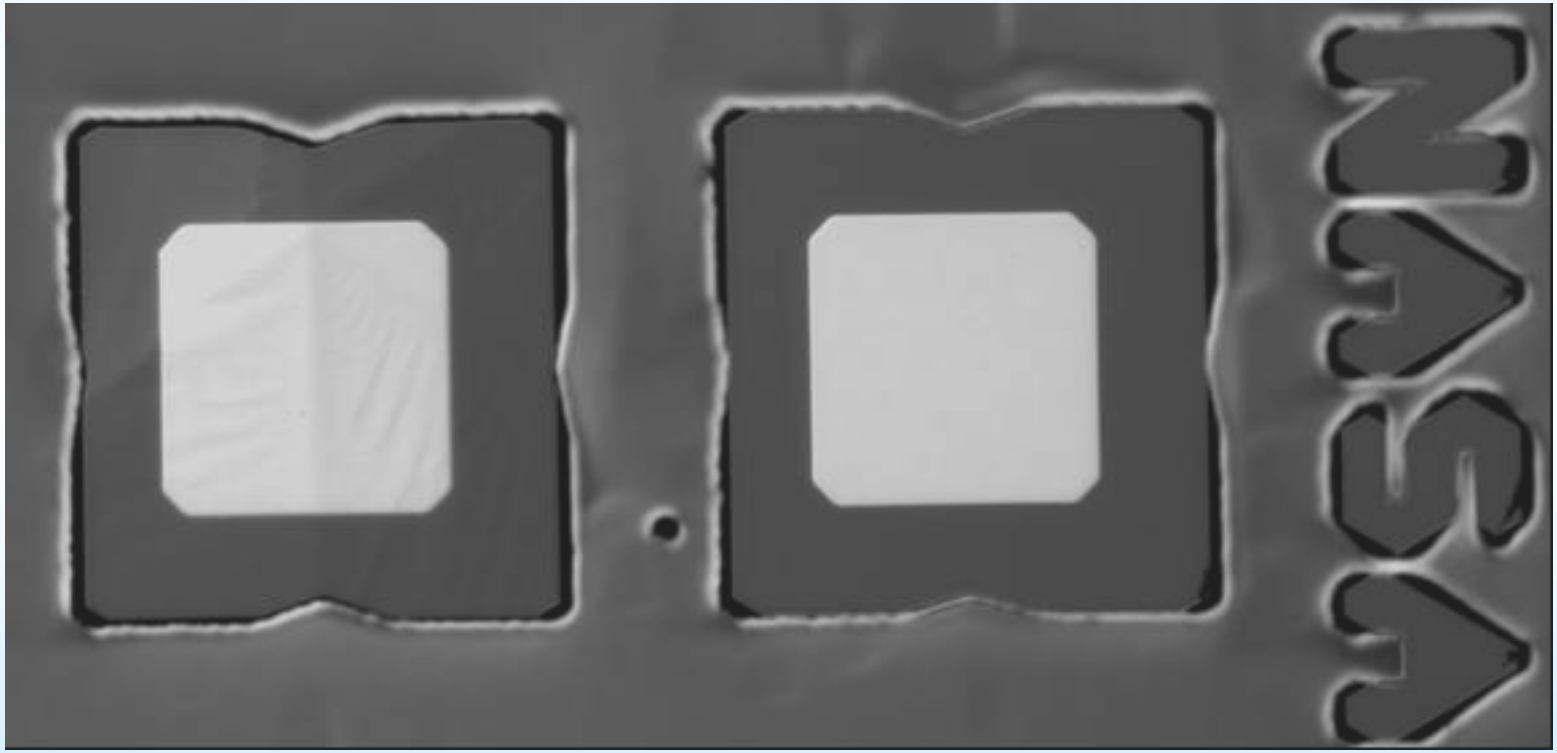
- WIDE RANGE OF APPLICATIONS
  - EMISSION MONITORING
  - ENGINE HEALTH MONITORING
  - ACTIVE COMBUSTION CONTROL
  - HYDROCARBON FUEL LEAK DETECTION
  - FIRE SAFETY
- PROTOTYPE SENSOR PACKAGE FABRICATED
- TWO APPROACHES
  - ALLOY ON SiC SUBSTRATE
  - REACTIVE INSULATOR APPROACH

PACKAGED SiC-BASED SENSOR

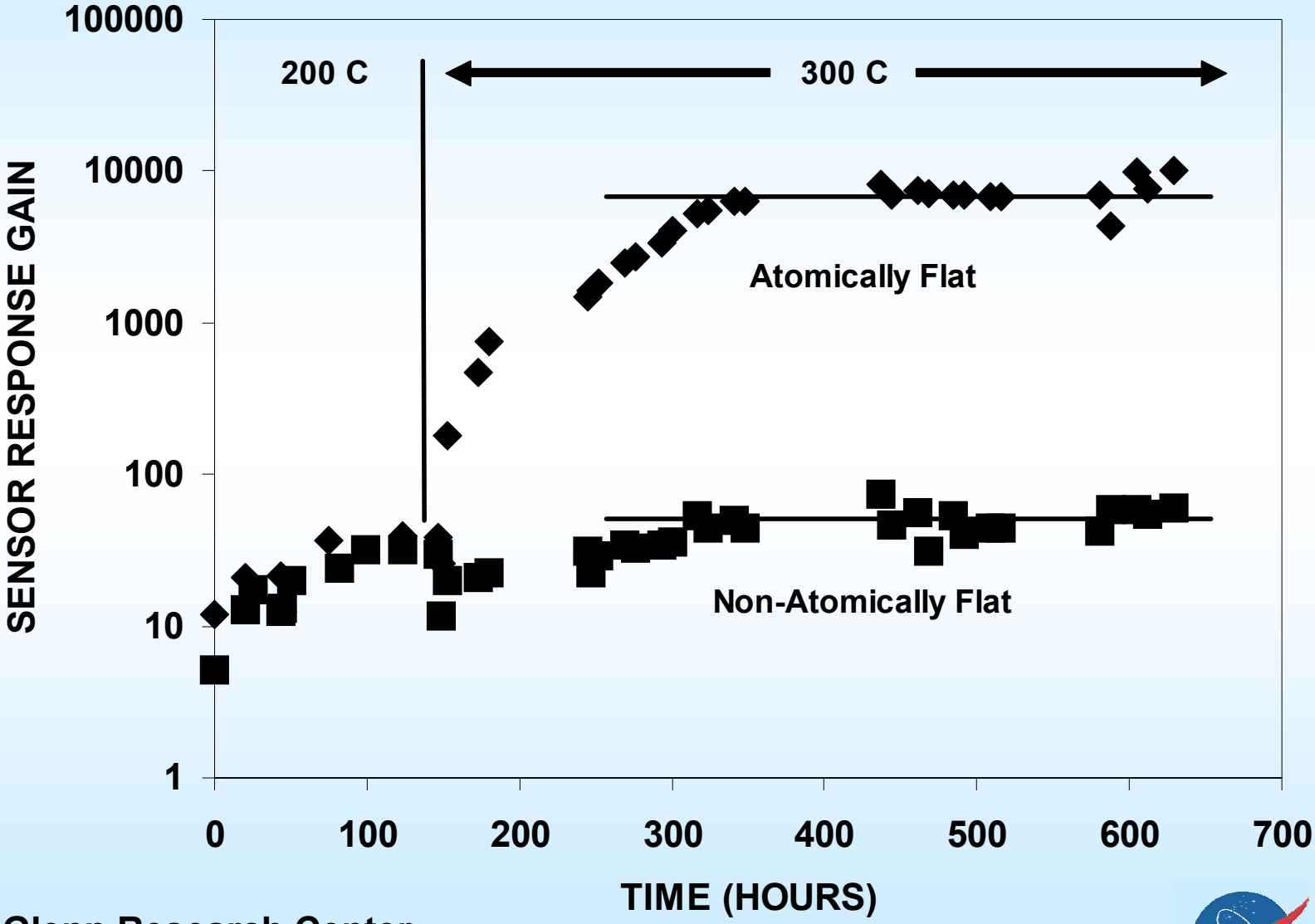


Pt/SiC SCHOTTKY DIODES TESTED SIDE BY SIDE ON SAME CHIP: ATOMICALLY FLAT AND NON-ATOMICALLY FLAT

Non-Atomically Flat Atomically Flat



COMPARISON OF SENSOR GAIN TO 0.5% HYDROGEN BETWEEN Pt/SiC SENSORS DEPOSITED ON ATOMICALLY FLAT SIC (♦) AND NON-ATOMICALLY FLAT SIC (■).



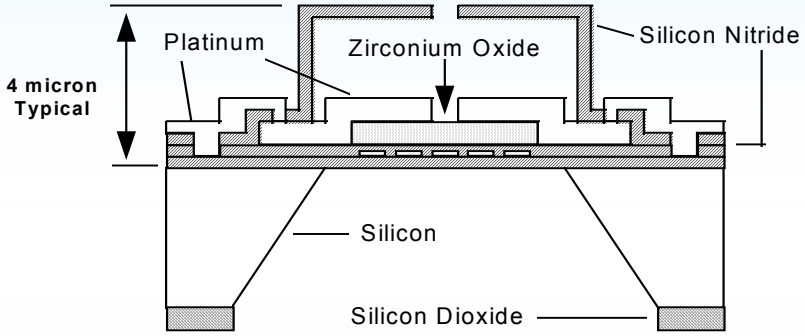
MICROFABRICATED OXYGEN SENSOR TECHNOLOGY

- **MICROFABRICATED AND MICROMACHINED FOR MINIMAL SIZE, WEIGHT AND POWER CONSUMPTION (LESS THAN 2 W FOR 600 C OPERATION)**

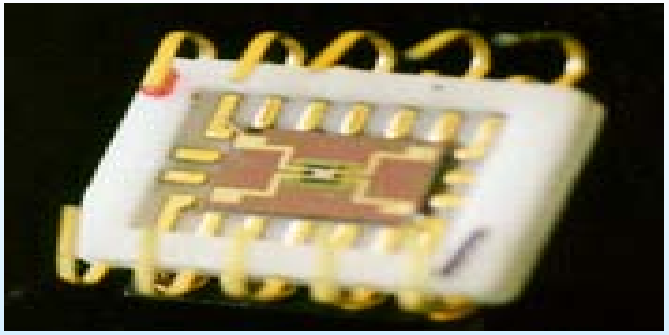
- **AMPEROMETRIC OPERATION ALLOWS MEASUREMENT OF OXYGEN OVER A WIDE CONCENTRATION RANGE (0-100%)**

- **CHAMBER STRUCTURE CONTROLS OXYGEN DIFFUSION RATE**

- **INCORPORATION OF OXYGEN SENSOR WITH OTHER SENSORS (E.G. HYDROGEN) IN THE SAME PACKAGE PLANNED**



Not to scale:



ZrO2 Oxygen Sensor

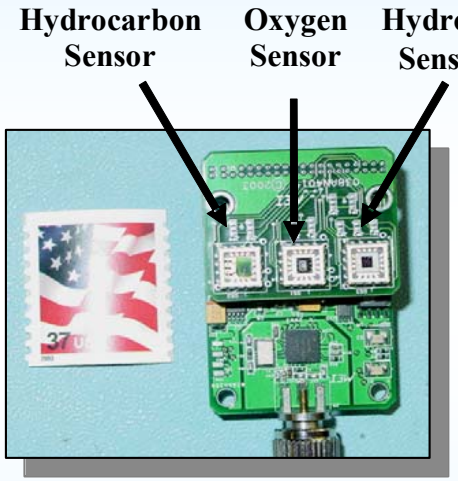
SENSOR SYSTEM DEVELOPMENT

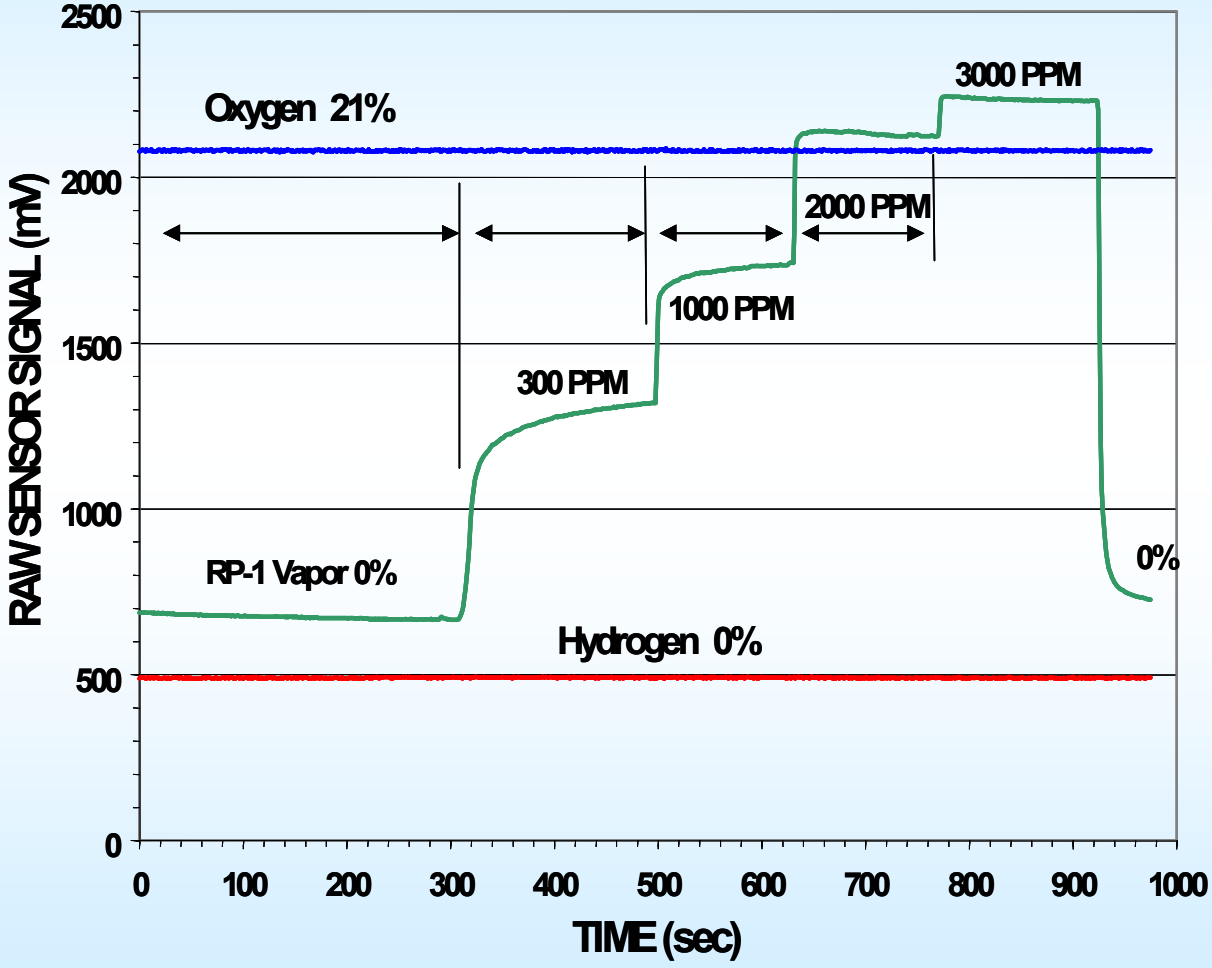
- EACH SENSOR PLATFORM PROVIDES QUALITATIVELY VERY DIFFERENT TYPES OF INFORMATION ON THE ENVIRONMENT
- SENSOR ARRAY VARIES WITH APPLICATION/MICROFABRICATION TECHNIQUES MANDATORY
- BASIS CHEMICAL SENSOR FEATURES:
  - RESPONSE TIME, SENSITIVITY, SELECTIVITY, STABILITY
  - BATCH FABRICATION, PROCESSING REPRODUCIBILITY, CONTROL OF STRUCTURE
  - TAILOR SENSOR SYSTEM FOR THE APPLICATION
- SUPPORTING TECHNOLOGIES NECESSARY
  - PACKAGING (OFTEN UP TO 70% OF OVERALL SENSOR COST)
  - SIGNAL CONDITIONING AND PROCESSING
  - SOFTWARE (E.G. NEURAL NET PROCESSING, MODELING)
  - POWER AND COMMUNICATION

See for example: G. W. Hunter, C.C. Liu, D. Makel, Microfabricated Chemical Sensors For Aerospace Applications, MEMS Handbook, CRC Press LLC, ed. M. Gad-el-Hak, Ch. 22, 2001.

- POSSIBLE STEPS NEEDED FOR BROAD INCLUSION OF SENSORS INTO INTELLIGENT SYSTEMS
  - "LICK AND STICK" TECHNOLOGY (EASE OF APPLICATION)
  - RELIABILITY
  - ORTHOGONALITY
  - CROSS-CORRELATION
  - REDUNDANCY

“LICK AND STICK” LEAK SENSOR SYSTEM DEMONSTRATION



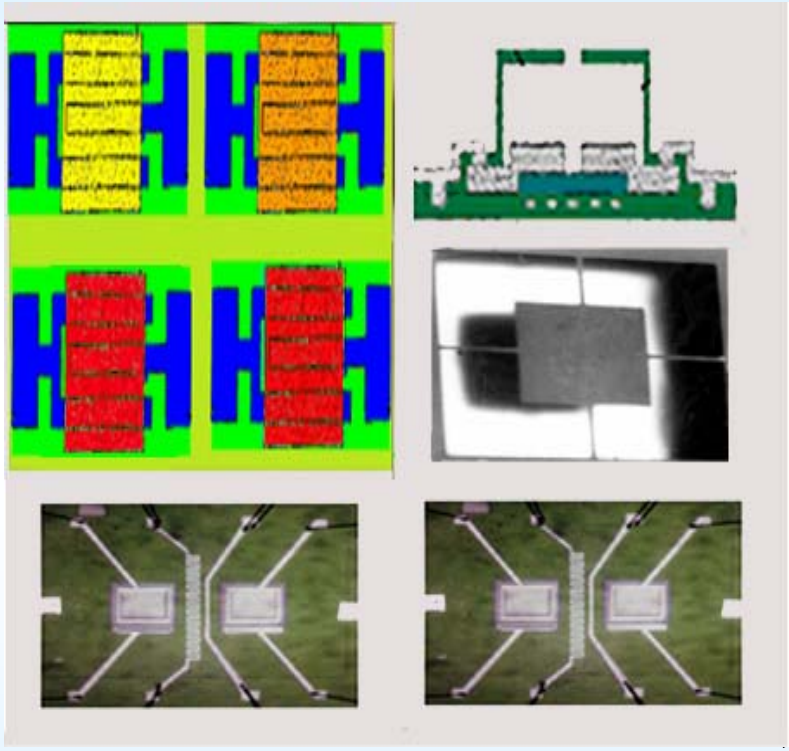


HIGH TEMPERATURE GAS SENSOR ARRAY
HIGH TEMPERATURE ELECTRONIC NOSE

SnO2 Resistor

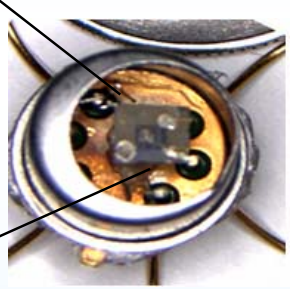
TiO2 Resistor

Electrochemical Oxygen Sensor



Selectively Filtered SnO2 Resistors

SiC-Based Pressure Sensor



Metal-SiC Schottky diodes

Metal-Reactive Insulator SiC Schottky diodes

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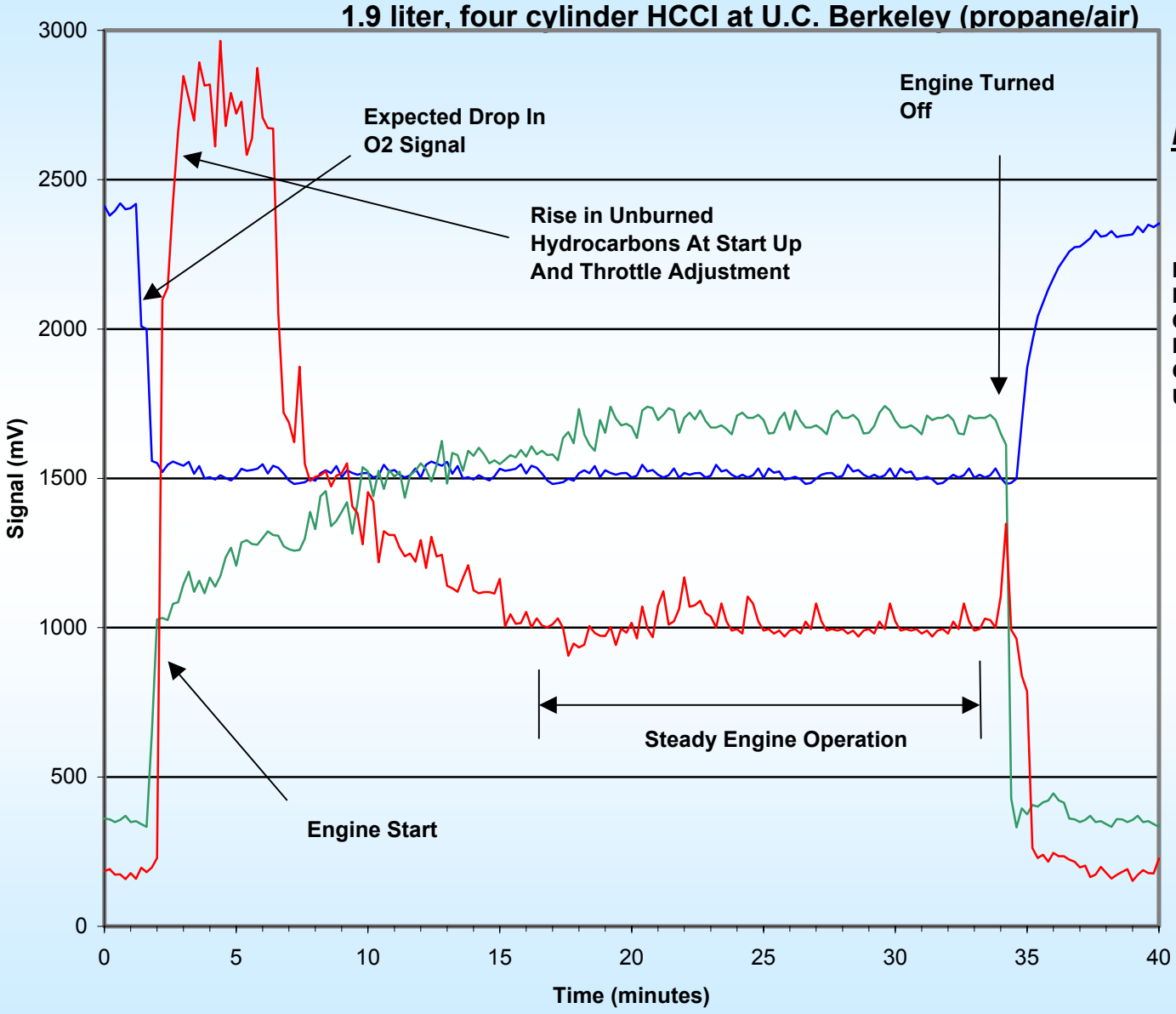
Harsh Environment Demonstration Testing



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Exhaust Gas Temperature = 337 C
Phi= 0.35
O2=14%
NOx<5 PPM
CO =1400 PPM
UHC =1200 PPM

GLENNAN MICROSYSTEMS INITIATIVE

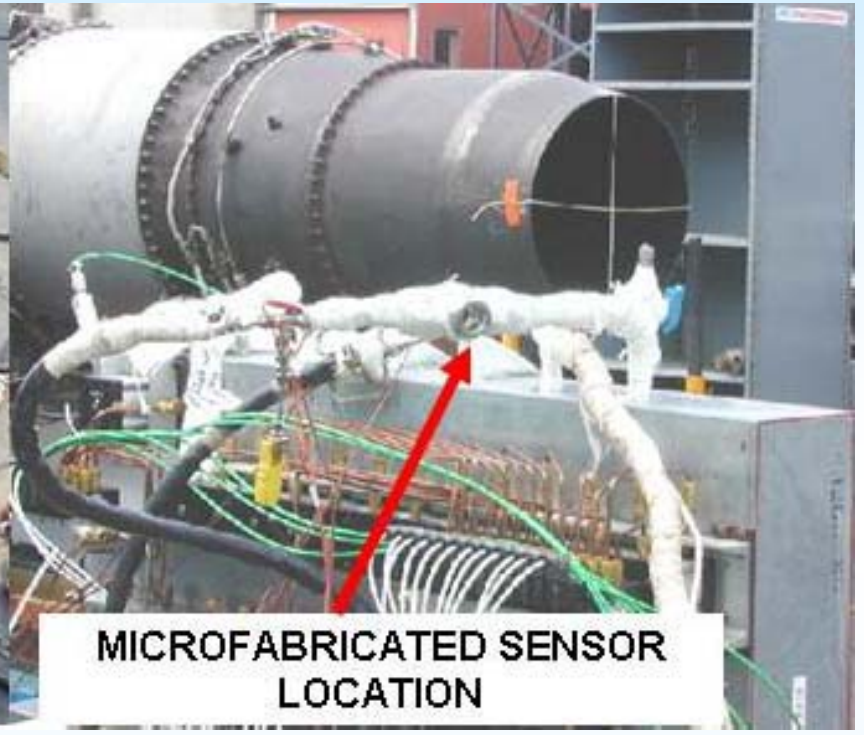
THE OHIO STATE UNIVERSITY

Glenn Research Center

Instrumentation and Controls Division

MICRO SENSORS TESTED ATOUTLET OF THE JT-12 JET ENGINE

Rake Sampling System At The Outlet Of The JT-12 Jet Engine.



Location Of The Sensors In The Flow Stream Of The Rake

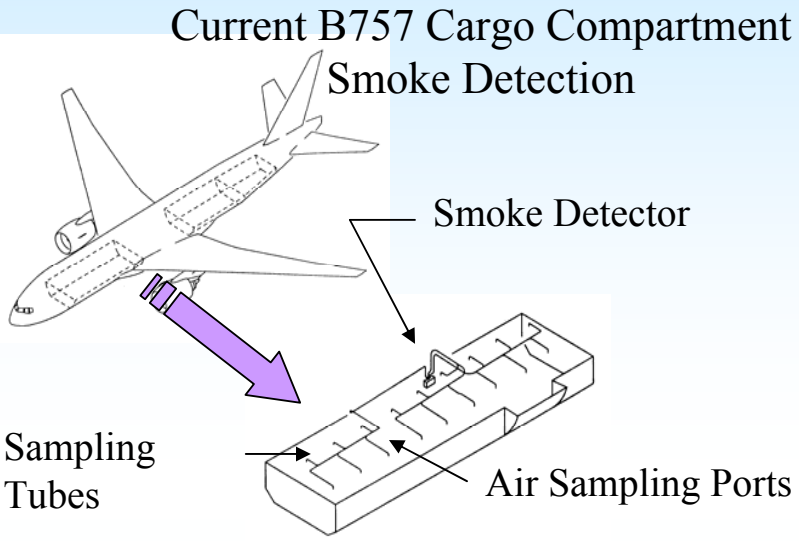
HIGH TEMPERATURE OPERATIONAL CAPABILITY AN OF THE SENSORS ALLOW PLACEMENT SIGNIFICANTLY CLOSER TO THE ENGINE OUTLET THAN TRADITIONAL EQUIPMENT.

Micro-Fabricated Gas Sensors for Low False Alarms

FEATURES

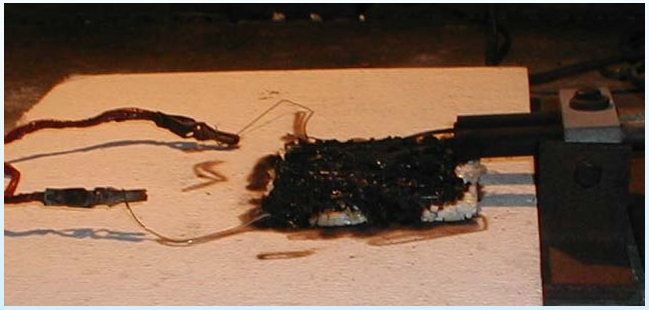
- MICROFABRICATED GAS SENSOR ARRAY ESP. CO/CO_2
  - ➢CENTRAL TO APPROACH
  - ➢TWO APPROACHES TO CO2 DETECTION
  - ➢MINIMAL SIZE/WEIGHT/POWER
- CHEMICAL GAS SENSORS PROVIDE GASEOUS PRODUCT-OF-COMBUSTION INFORMATION
  - ➢SENSOR ARRAY CAN DETECT RANGE OF GAS SPECIES
  - ➢TO BE COMBINED WITH INTELLIGENT SOFTWARE FOR PATTERN RECOGNITION
- COMBINE WITH MICROPARTICULATE DETECTORS
- BENEFITS

➢DISCRIMINATE FIRES FROM NON-FIRES



Particulate sensor contrasted with traditional macroscale classifier.

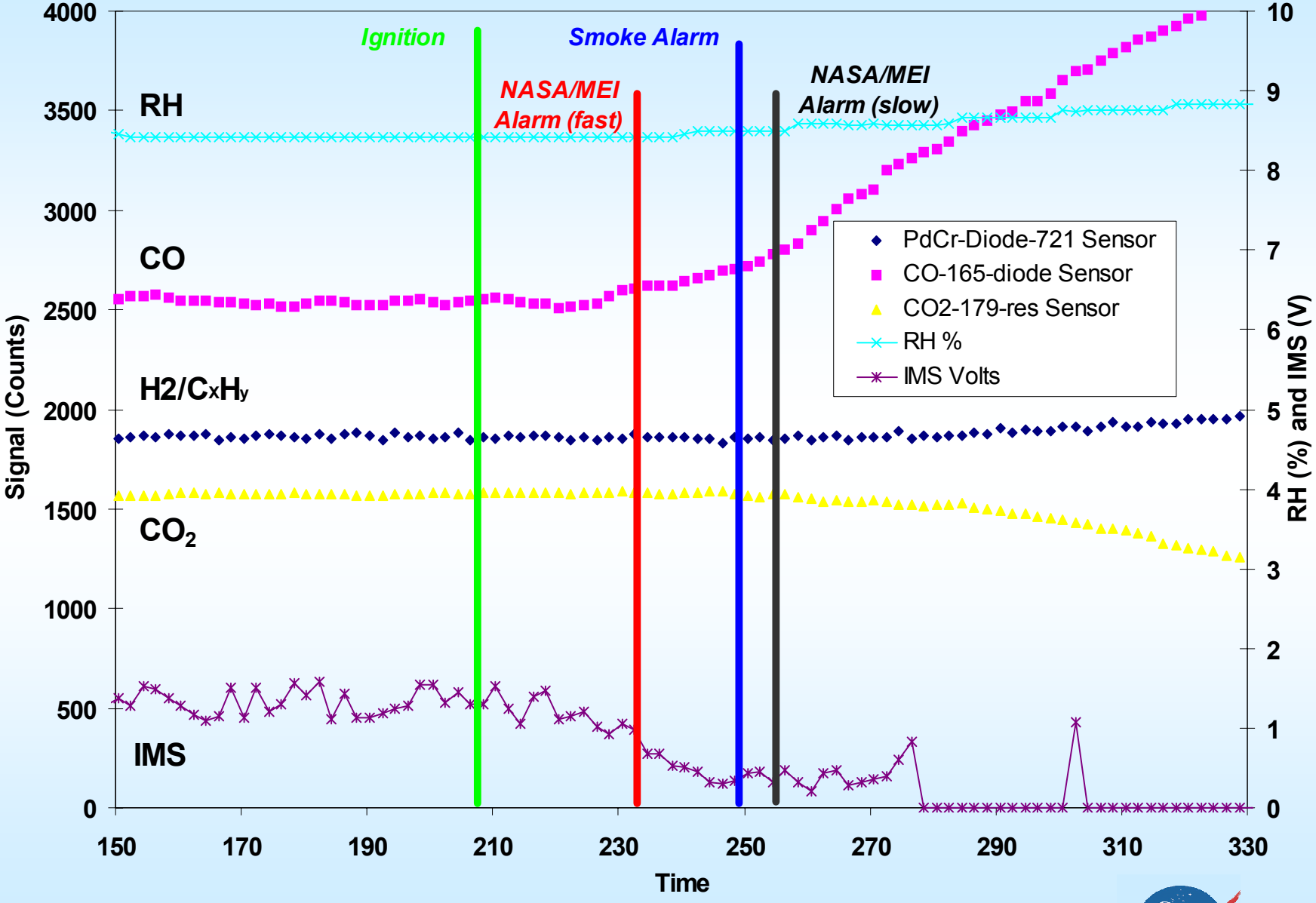
FAA Cargo Bay Fire Simulation Testing
Boeing 707 luggage compartment and the FAA "Biscuit"



FAA Cargo Bay False Alarm Testing
No False Alarms

Test#	Detection System(s) Exposed	Exposed to	Test Duration (secs)	Generic Alarm Time (secs)	Alarm Time with Algorithm X (secs)	Alarm Time with Algorithm Y (secs)	Alarm Time with Algorithm Z (secs)
1	Generic/Makel	Dust		15	No Alarm	No Alarm	No Alarm
2	Generic/Makel	Dust		3	No Alarm	No Alarm	No Alarm
3	Generic/Makel	Dust		2	No Alarm	No Alarm	No Alarm
4	Generic/Makel	Dust		41	No Alarm	No Alarm	No Alarm
5	Generic/Makel	Dust		1	No Alarm	No Alarm	No Alarm
6	Generic/Makel	Dust		2	No Alarm	No Alarm	No Alarm
7	Generic/Makel	Dust		3	No Alarm	No Alarm	No Alarm
8	Generic/Makel	Dust		1	No Alarm	No Alarm	No Alarm
9	Generic/Makel	Dust		1	No Alarm	No Alarm	No Alarm
10	Generic/Makel	Dust		2	No Alarm	No Alarm	No Alarm
11	Generic	Water vapor	300	9			
12	Makel	Water vapor	340	N/A	No Alarm	No Alarm	No Alarm
13	Makel	Water vapor		N/A	No Alarm	No Alarm	No Alarm
14	Generic	Water vapor	20	3			
15	Generic	Water vapor	60	2			
16	Makel	Water vapor	60	N/A	No Alarm	No Alarm	No Alarm

FAA Cargo Bay Fire Testing



SUMMARY

- AEROSPACE AND HARSH ENVIRONMENT APPLICATIONS REQUIRE A RANGE OF CHEMICAL SENSING TECHNOLOGIES
- NEW FAMILY OF GAS SENSOR TECHNOLOGY BEING DEVELOPED TO MEET THESE NEEDS USING:
  - MICROFABRICATION AND MICROMACHINING TECHNOLOGY
  - NANOMATERIALS
  - SiC-BASED SEMICONDUCTOR TECHNOLOGY
- TECHNOLOGY BEST APPLIED WITH STRONG INTERACTION WITH USER/TAILOR SENSOR FOR NEEDS OF APPLICATION
- A VARIETY OF SENSOR TYPES AND PLATFORMS BEING DEVELOPED
- SUPPORTING TECHNOLOGIES NECESSARY
- RESOLUTION OF A NUMBER OF TECHNICAL CHALLENGES: SENSOR ARRAYS
  - LEAK DETECTION
  - HIGH TEMPERATURE ELECTRONIC NOSE
  - FIRE DETECTION
- LONG-TERM: INTELLIGENT SYSTEMS
  - RELIABILITY
  - REDUNDANCY
  - ORTHOGONALITY
  - CROSS-CORRELATION