Hydrogen Fuel Detection Based on Smart Sensor Systems

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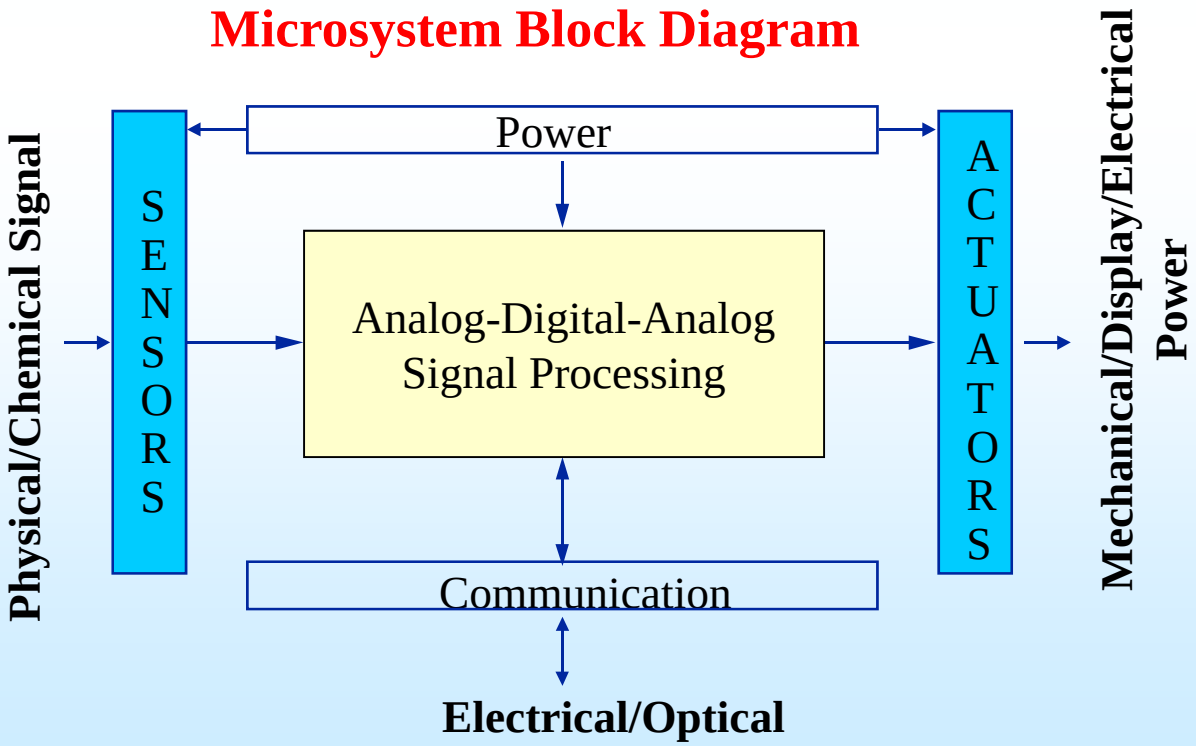
OUTLINE

- INTRODUCTION: SMART SENSOR SYSTEMS
- HYDROGEN SENSING TECHNOLOGY
  - ➢MICROSENSOR BASED PLATFORM
  - ➢SIC BASED GAS SENSORS
  - ➢“LICK AND STICK” HARDWARE
- SENSOR SYSTEM DEMONSTRATION AND APPLICATION
  - ➢LEAK DETECTION/SYSTEM SAFETY AND OPERATIONS
  - ➢FIRE DETECTION SYSTEMS/EMISSIONS MONITORING
- MICROSENSORS BASED ON NANOSTRUCTURED MATERIALS
- SUMMARY AND CONCLUSION

MICROSYSTEMS TECHNOLOGY

- THIS PRESENTATION DISCUSSES A RANGE OF GAS SENSOR TECHNOLOGIES
- EXAMPLES REVOLVE AROUND MICROSYSTEMS TECHNOLOGY
- BASIC APPROACH: DRIVE CAPABILITIES TO THE LOCAL LEVEL/DISTRIBUTED SMART SYSTEMS
- A MAJOR POINT OF THIS PRESENTATION IS THAT CORE INTELLIGENT CHEMICAL MICROSYSTEM TECHNOLOGY CAN MEET THE NEEDS OF A RANGE OF APPLICATIONS



SENSOR SYSTEM IMPLEMENTATION

- OBJECTIVE: A SELF-AWARE INTELLIGENT SYSTEM COMPOSED OF SMART COMPONENTS MADE POSSIBLE BY SMART SENSOR SYSTEMS
- SENSOR SYSTEMS ARE NECESSARY AND ARE NOT JUST GOING TO SHOW UP WHEN NEEDED/TECHNOLOGY BEST APPLIED WITH STRONG INTERACTION WITH USER
- SENSOR SYSTEM IMPLEMENTATION OFTEN PROBLEMATIC
  - LEGACY SYSTEMS
  - CUSTOMER ACCEPTANCE
  - LONG-TERM VS SHORT-TERM CONSIDERATIONS
  - SENSORS NEED TO BUY THEIR WAY INTO AN APPLICATION
- SENSOR DIRECTIONS INCLUDE:
  - INCREASE MINIATURIZATION/INTEGRATED INTELLIGENCE
  - MULTIFUNCTIONALITY/MULTIPARAMETER MEASUREMENTS/ORTHOGONALITY
  - INCREASED ADAPTABILITY
  - COMPLETE STAND-ALONE SYSTEMS (“LICK AND STICK” SYSTEMS)
- POSSIBLE LESSONS LEARNED
  - SENSOR SYSTEM NEEDS TO BE TAILORED FOR THE APPLICATION
  - MICROFABRICATION IS NOT JUST MAKING SOMETHING SMALLER
  - ONE SENSOR OR EVEN ONE TYPE OF SENSOR OFTEN WILL NOT SOLVE THE PROBLEM: THE NEED FOR SENSOR ARRAYS
  - SUPPORTING TECHNOLOGIES OFTEN DETERMINE SUCCESS OF A SYSTEM

BASIC APPROACH:
MAKE AN INTELLIGENT SYSTEM FROM SMART COMPONENTS

POSSIBLE STEPS TO REACH INTELLIGENT SYSTEMS

- **"LICK AND STICK" TECHNOLOGY (EASE OF APPLICATION)**
  - **Micro and nano fabrication to enable multipoint inclusion of sensors, actuators, electronics, and communication throughout the vehicle without significantly increasing size, weight, and power consumption. Multifunctional, adaptable technology included.**
- **RELIABILITY:**
  - **Users must be able to believe the data reported by these systems and have trust in the ability of the system to respond to changing situations e.g. decreasing sensors should be viewed as decreasing the available information flow about a vehicle. Inclusion of intelligence more likely to occur if it can be trusted.**
- **REDUNDANCY AND CROSS-CORRELATION:**
  - **If the systems are easy to install, reliable, and do not increase weight/complexity, the application of a large number of them is not problematic allowing redundant systems, e.g. sensors, spread throughout the vehicle. These systems will give full-field coverage of the engine parameters but also allow cross-correlation between the systems to improve reliability of sensor data and the vehicle system information.**
- **ORTHOGONALITY:**
  - **Systems should each provide a different piece of information on the vehicle system. Thus, the mixture of different techniques to "see, feel, smell, hear" as well as move can combine to give complete information on the vehicle system as well as the capability to respond to the environment.**

BASE PLATFORM SENSOR TECHNOLOGY

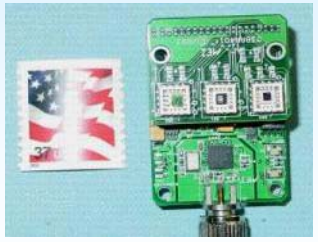
Integration of Micro Sensor Combinations into Small, Rugged Sensor Suites

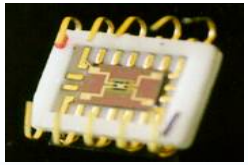
Example Applications: AEROSPACE VEHICLE FIRE, FUEL LEAKS, EMISSIONS, ENVIRONMENTAL MONITORING, CREW HEALTH, SECURITY

Multi Species Fire Sensors for Aircraft Cargo Bays and Space Applications

Environmental monitoring (ISS Whitesand Testing)

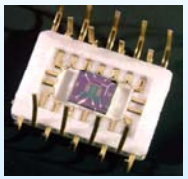
"Lick and Stick" Space Launch Vehicle Leak Sensors with Power and Telemetry



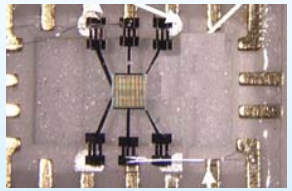


Oxygen Sensor

SiC Hydrocarbon Sensor

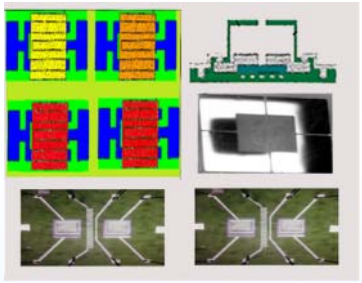


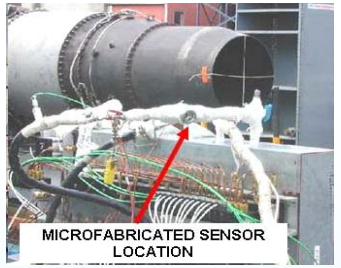
H2 Sensor



Nanocrystalline Tin Oxide NOx and CO Sensor

Aircraft Propulsion Exhaust High Temperature Electronic Nose





Hydrazine EVA Sensors (ppb Level Detection)

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

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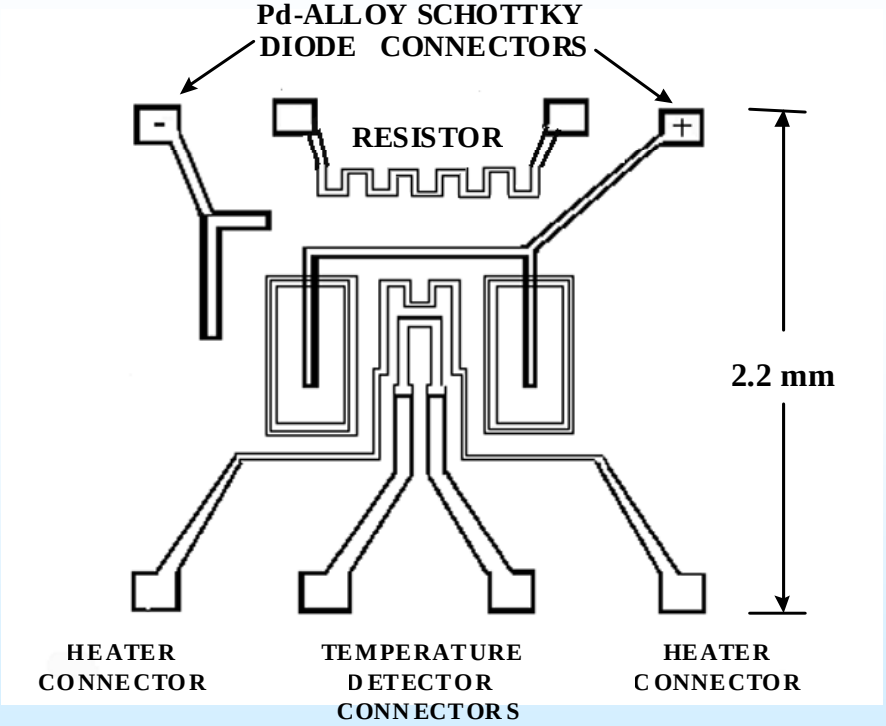
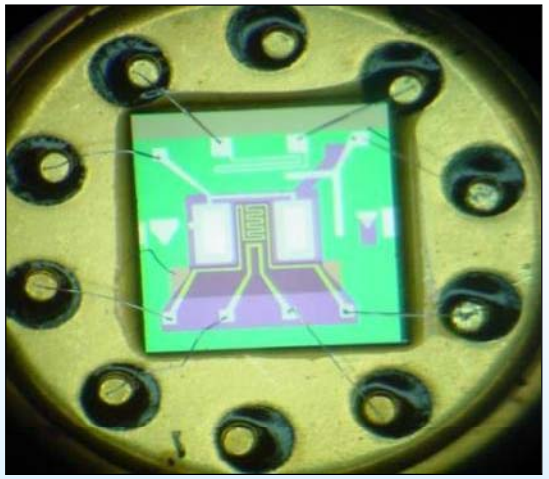
HYDROGEN LEAK SENSOR TECHNOLOGY

- **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 LEVEL TO 100%**





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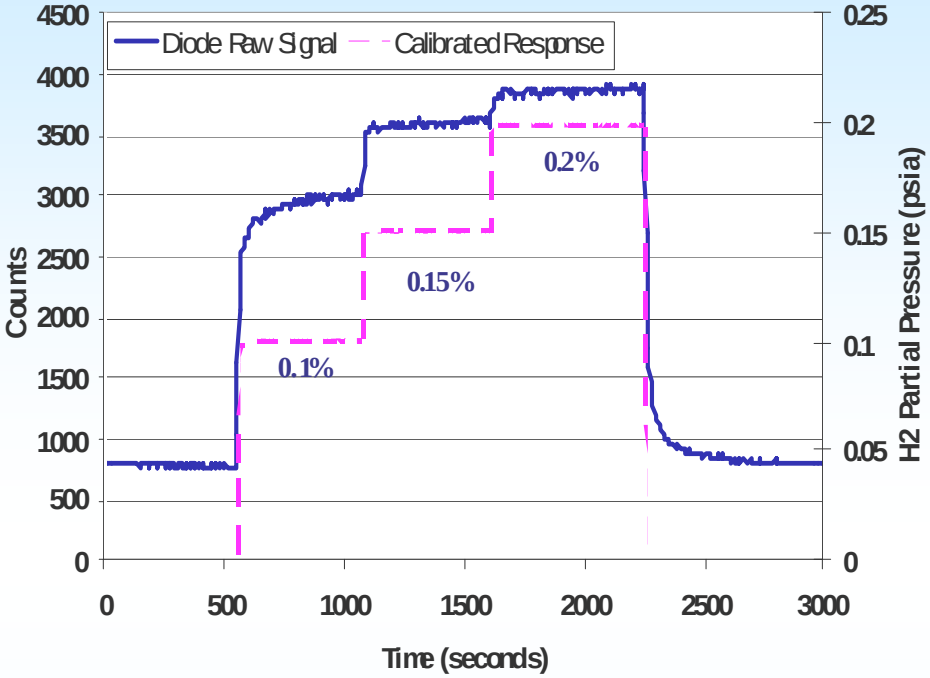
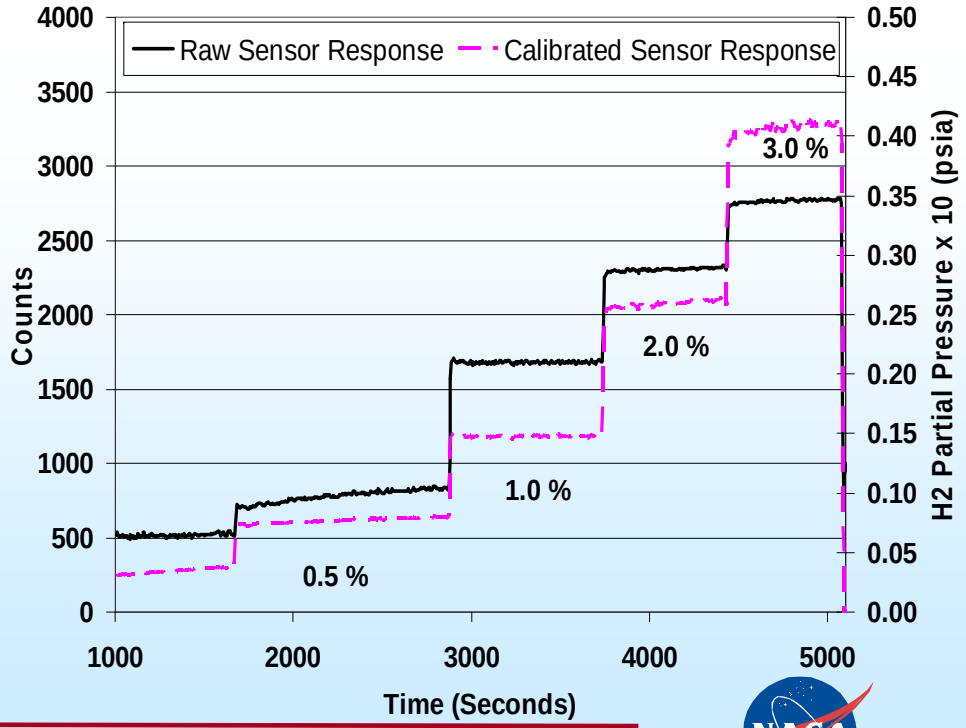
Pd Alloy Based Schottky Diode Response To Hydrogen: Both the Raw Signal and Calibrated Response.



Pd Alloy Based Schottky Diode Response To Hydrogen: Both the Raw Signal and Calibrated Response.

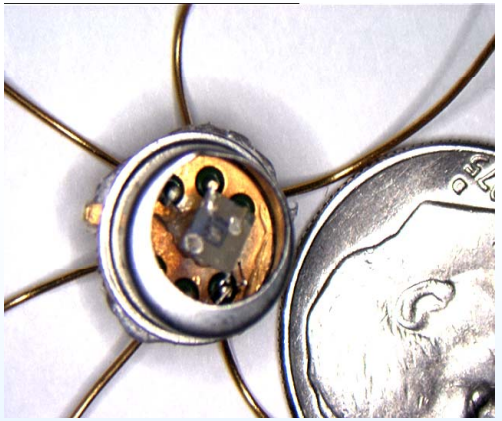
Pd Alloy Based Resistor Response To Hydrogen: Both Raw Signal And Calibrated Response.



SiC-BASED GAS SENSOR DEVELOPMENT

- THE USE OF SiC SEMICONDUCTORS ALLOWS SENSOR OPERATION AT TEMPERATURES WHICH ALLOW THE DETECTION OF HYDROCARBONS AND NOx
- INERT MATERIAL OPERATIONAL IN HIGH TEMPERATURE, CORROSIVE ENVIRONMENTS
- SCHOTTKY DIODE DESIGN FOR HIGH SENSISTIVITY
- WIDE RANGE OF APPLICATIONS
  - EMISSION MONITORING
  - ENGINE HEALTH MONITORING
  - ACTIVE COMBUSTION CONTROL
  - HYDROCARBON FUEL LEAK DETECTION
  - FIRE SAFETY
- SENSOR TESTED IN ENGINE ENVIRONMENTS
- APPROACHES
  - ALLOY ON SiC SUBSTRATE
  - REACTIVE INSULATOR APPROACH
  - BARRIER LAYER
  - ATOMICALLY FLAT SiC

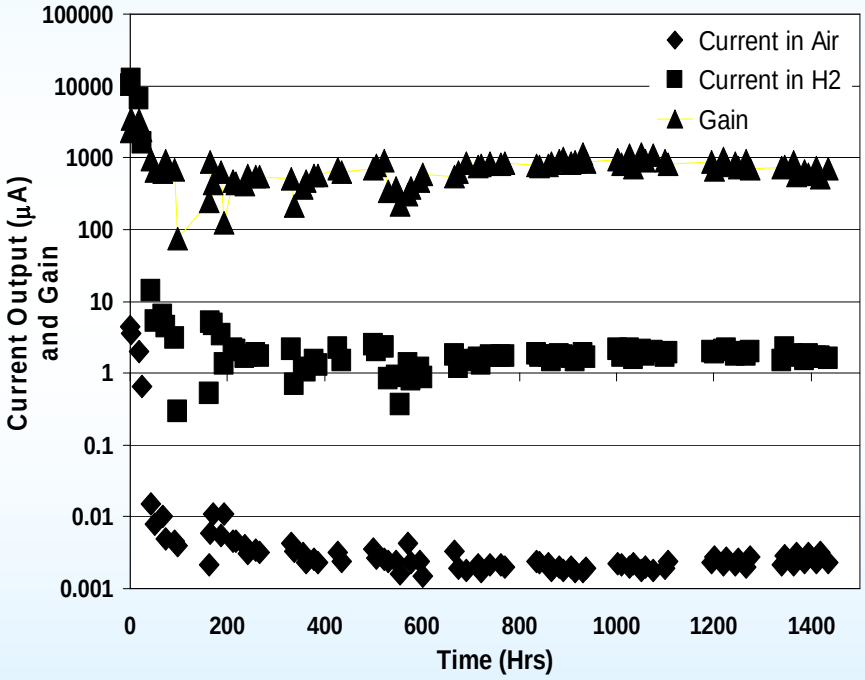
PACKAGED SiC-BASED SENSOR



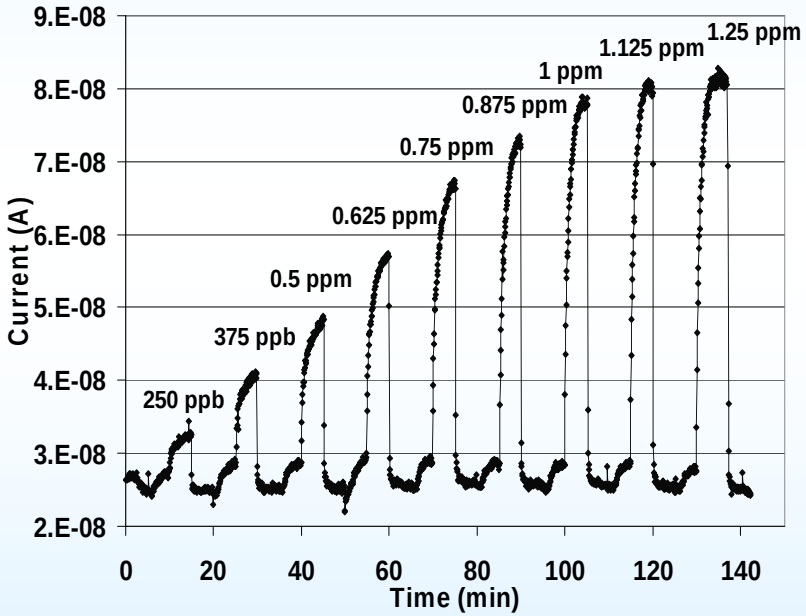
- NOMINATED FOR NASA INVENTION OF THE YEAR IN 2OO9

SiC SCHOTTKY DIODE GAS SENSOR

- MULTIPLE CONFIGURATIONS AVAILABLE
- H2 CONCENTRATIONS MEASURED AS LOW AS 250 ppb
- A RANGE OF HYDROCARBONS CAN BE MEASURED
- EXTENDED OPERATION TIME DEMONSTRATED AT HIGHER TEMERATURES
- PLANNED USED IN ENGINE EMISSION TESTS IN THE NEAR FUTURE

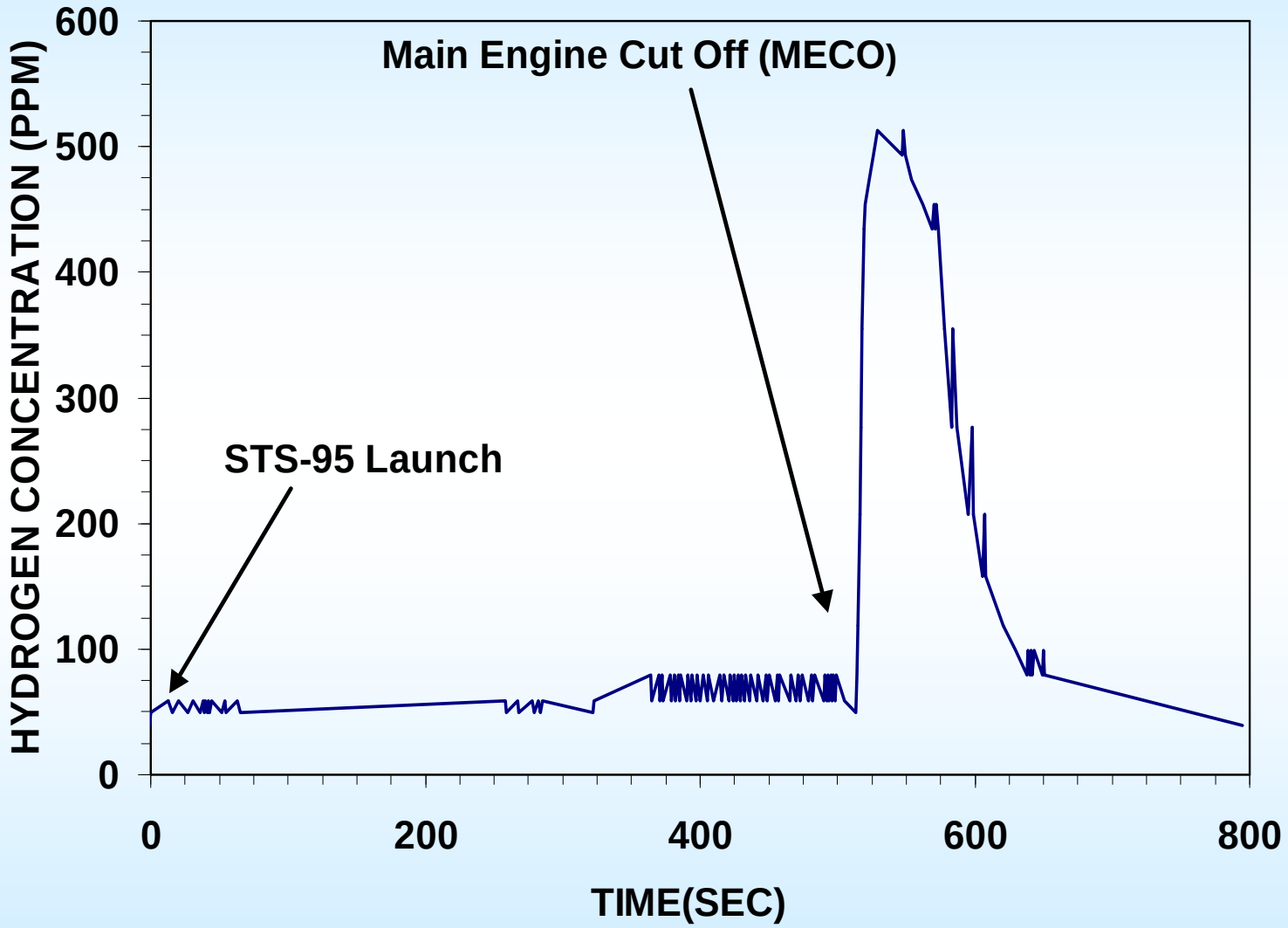


Pd/PdO$_X$/SiC SCHOTTKY DIODE SENSOR RESPONSE AT 450˚C BIASED AT 1V. BASELINE IN AIR, 0.5% HYDROGEN IN NITROGEN, AND SENSOR GAIN



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

STS-95 Hydrogen Sensor Flight Data



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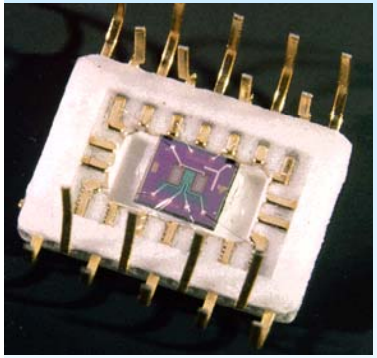
1995 R&D 100 AWARD WINNER

AUTOMATED HYDROGEN LEAK DETECTION SYSTEM ON NATURAL GAS POWERED CROWN VICTORIA ASSEMBLY LINE

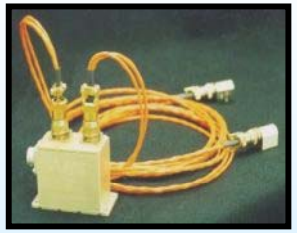
HYDROGEN LEAK SENSOR TECHNOLOGY



- **STATUS: OPERATIONAL SYSTEM ON ISS WITH ASSOCIATED HARDWARE**
- **BEING PREPARED FOR CREW LAUNCH VEHICLE IMPLEMENTATION**

1995 R&D 100 AWARD WINNER

NASA 2003 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

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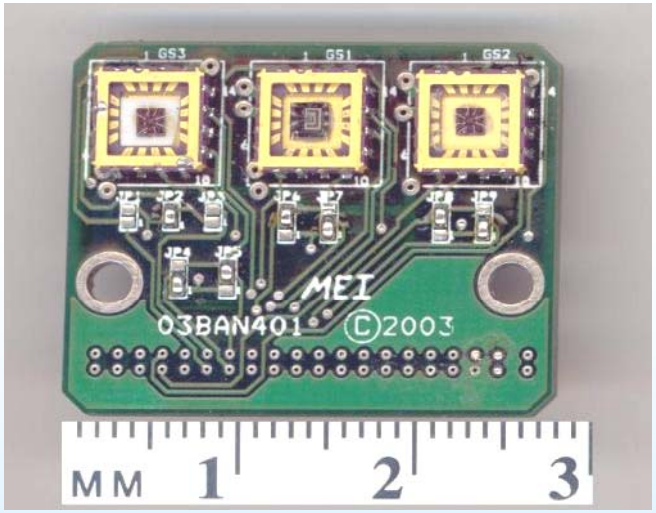
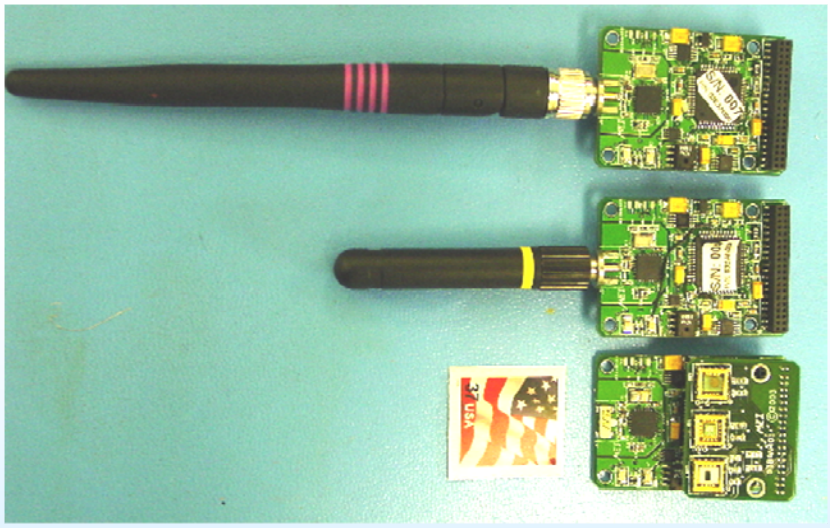
“LICK AND STICK” LEAK SENSOR SYSTEM

- SENSORS, POWER, AND TELEMETRY SELF-CONTAINED IN A SYSTEM NEAR THE SURFACE AREA OF A POSTAGE STAMP
- MICROPROCESSOR INCLUDED/SMART SENSOR SYSTEM
- VERIFY SYSTEM COMPATIBILITY WITH SPACE APPLICATIONS
- ADAPTABLE CORE SYSTEM WHICH CAN BE USED IN A RANGE OF APPLICATIONS
- BUILT-IN SELF CHECK, INTERNAL DATA TABLES
- MULTIPLE CONFIGURATIONS AVAILABLE



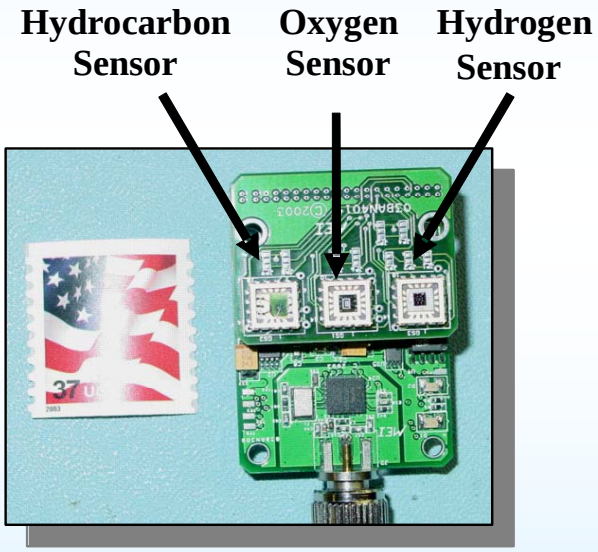
“Lick and Stick” Leak Detection Electronics and Three Sensors

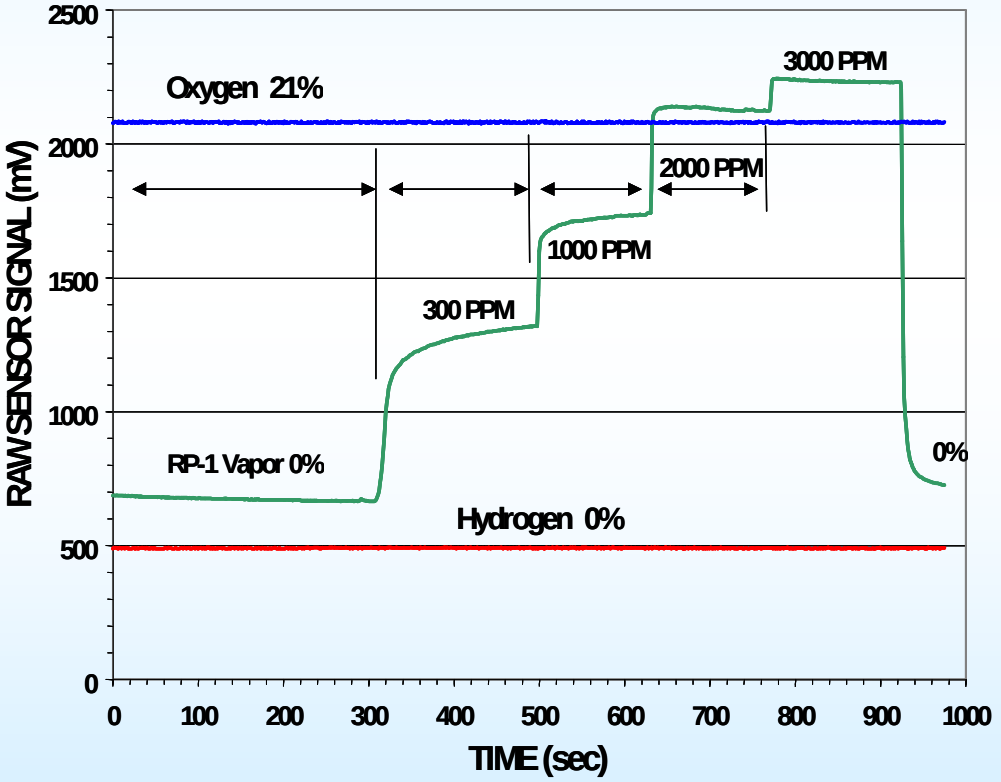


System configured with different wireless antennae.

"LICK AND STICK" LEAK SENSOR SYSTEM DEMONSTRATION

- WIRELESS DEMONSTRATION OF 3 SENSOR SYSTEM ACHIEVED
- MULTI-PARAMETER TECHNIQUE ALLOWING DETECTION OF BOTH FUEL AND OXYGEN
- QUALIFIED FOR CREW LAUNCH VEHICLE APPLICATIONS (HARDWIRED) FOR HYDROGEN DETECTION ONLY





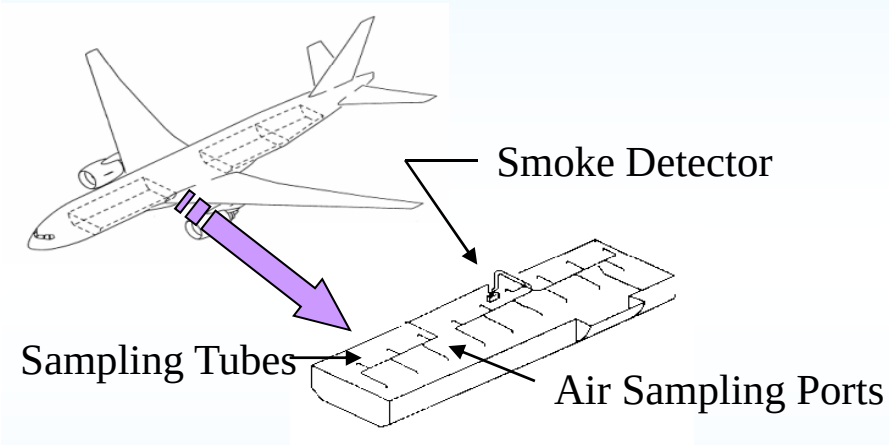
BASIC APPROACH: MEET THE NEEDS OF MULTIPLE APPLICATIONS BUILDING FROM A CORE SET OF SMART MICROSENSOR TECHNOLOGY

Micro-Fabricated Gas Sensors for Low False Alarms

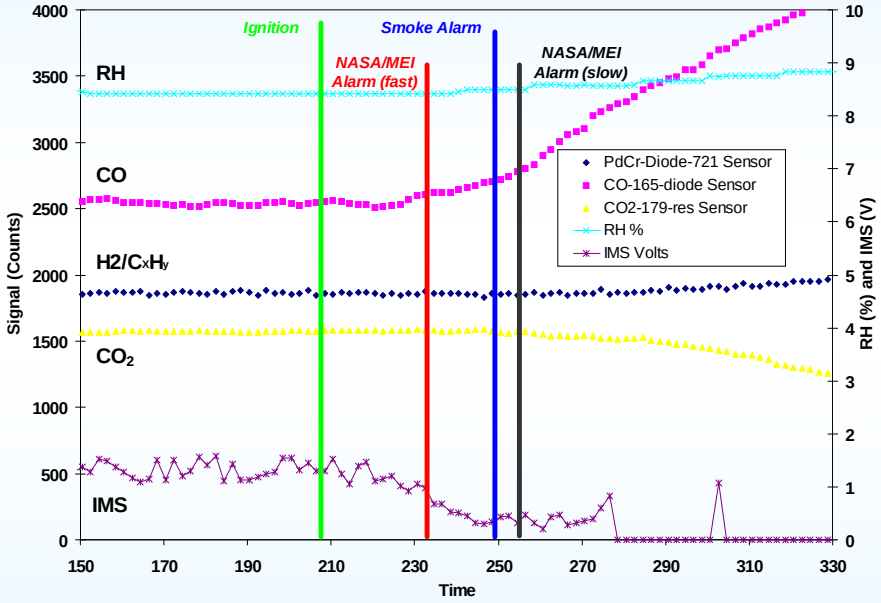
2005 R&D 100 AWARD WINNER

NASA 2005 TURNING GOALS INTO REALITY AA's CHOICE AWARD

- **AIM TO DECREASE FALSE ALARM RATE WHICH IS AS HIGH AS 200:1**
- **CHEMICAL GAS SENSORS PROVIDE GASEOUS PRODUCT-OF-COMBUSTION INFORMATION**
- **FAA TESTING: CONSISTENT DETECTION OF FIRES/NO FALSE ALARMS**

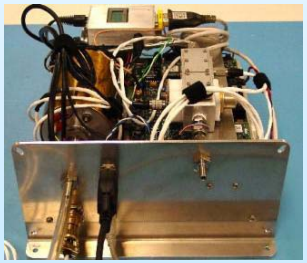


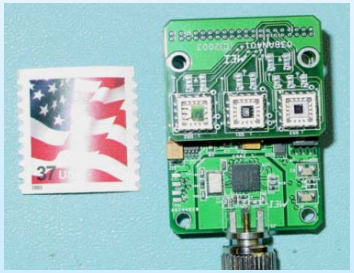
Current B757 Cargo Compartment Smoke Detection



FAA Cargo Bay Fire Test Data

TRANSITION AERONAUTICS HARDWARE INTO CORE "LICK AND STICK" SPACEFLIGHT HARDWARE PLATFORM





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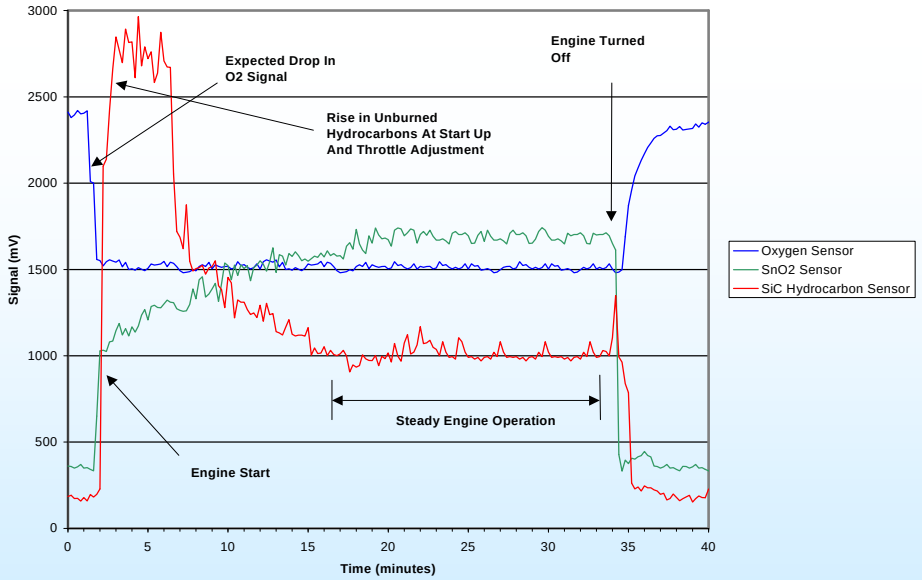
HIGH TEMPERATURE GAS SENSOR ARRAY
HIGH TEMPERATURE ELECTRONIC NOSE

- PLACEMENT OF SENSORS SIGNIFICANTLY CLOSER TO THE ENGINE OUTLET THAN TRADITIONAL EQUIPMENT ALLOWS REPLACEMENT OF INSTRUMENT RACKS
- SENSOR ARRAY BEING DEVELOPED FOR THIS APPLICATION: CO, CO2, OXYGEN, HYDROGEN, HYDROCARBONS, AND NOx
- NAVY FUNDED PROJECT: NEW PRODUCT LINE FROM MAKEL ENGINEERING, INC. FOR CO, CO2 AND O2 AVAIALBLE FOR TESTSTAND MEASUREMENTS
- QUANTATIVE VALUES FOR CO, CO2 AND O2;
  - CALIBRATION ON TESTSTAND FOLLOWED BY VERIFICATION WITH SCALING FACTOR ON ENGINE COMPANY TESTSTANDS



Early Demonstration of High Temperature Electronic Nose Concept

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

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METAL OXIDE NANOSTRUCTURES FOR CHEMICAL SENSOR DEVELOPMENT

Move Towards Nanostructures e.g. Tubes, Rods, Ribbons

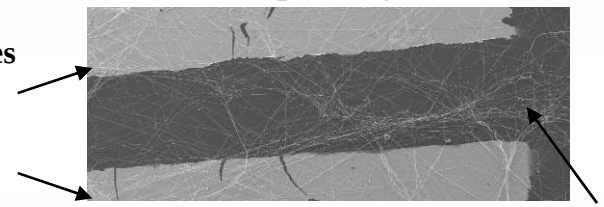
Develop Basic Tools To Enable Fabrication Of Repeatable Sensors Using Nanostructures

Approach 3 Basic Problems In Applying Nanostructures As Chemical Sensors

- ***Micro-Nano Contact Formation***
- ***Nanomaterial Structure Control***
- ***Range Of Nano Structured Oxides Available***

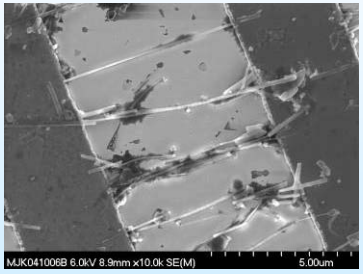
IMPROVE NANOSTRUCTURE TO MICROELECTRODE CONTACTS

Electrospinning



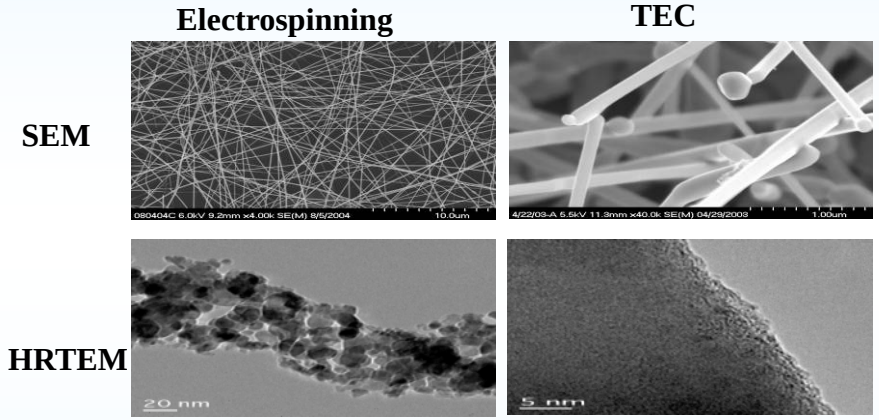
Bridging of electrospun SnO_2 nanofibers across electrodes.

Dielectrophoresis



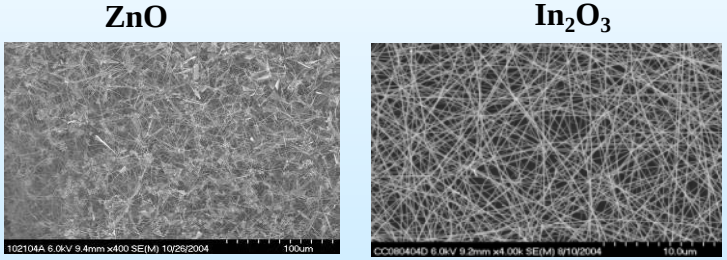
TiO2 Nanorods aligned by dielectrophoresis across interdigitated electrode patterns.

NANOMATERIAL STRUCTURE CONTROL



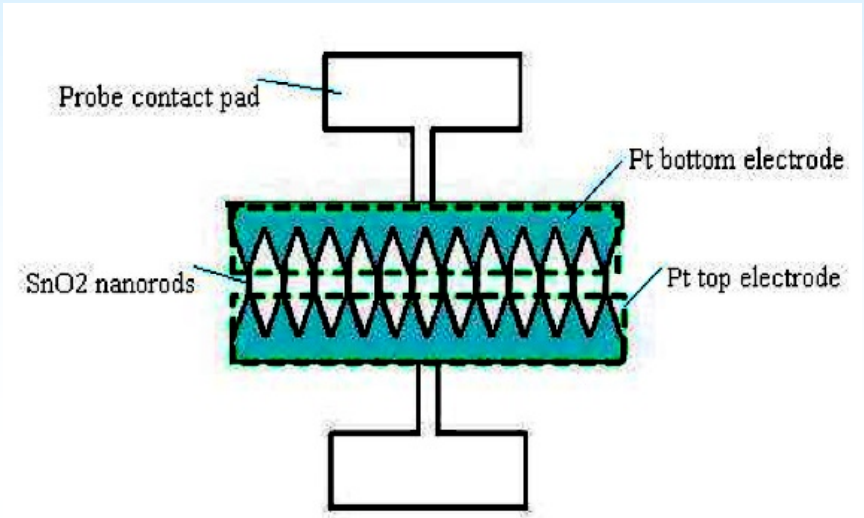
Different Processing of nanostructures produces different crystal structures

EXPAND RANGE OF NANOSTRUCTURES AVAILABLE

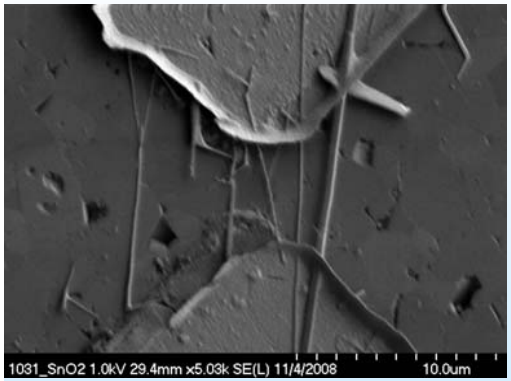


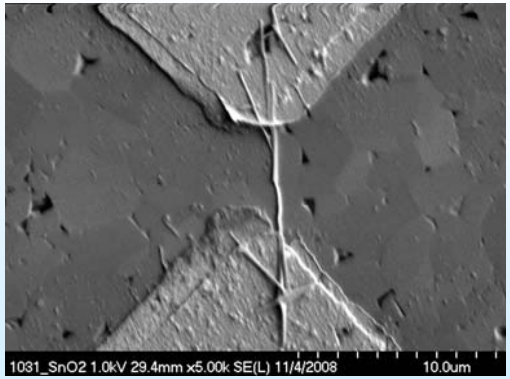
Multiple oxide nanostructured materials fabricated

MICRO-NANO CONTACTS
Microfabrication Applied To Nanotechnology

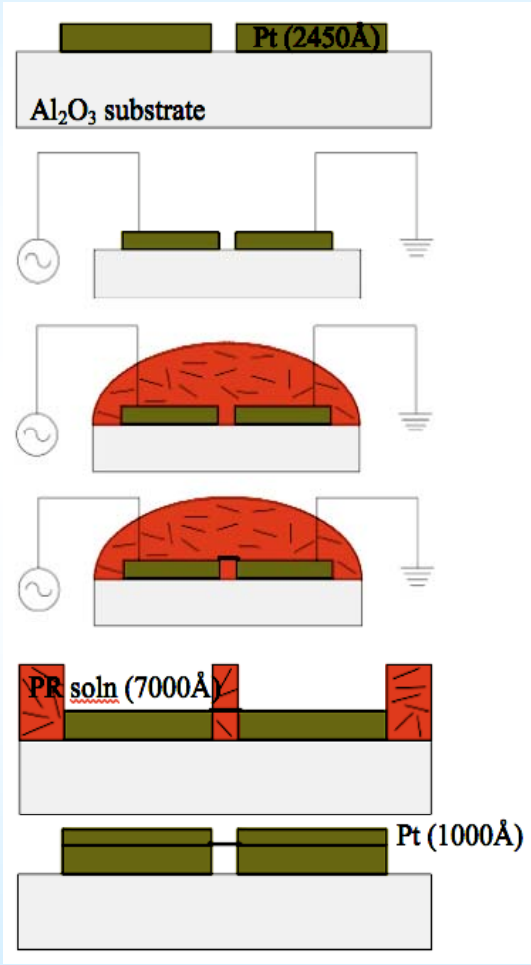


Sensor structure





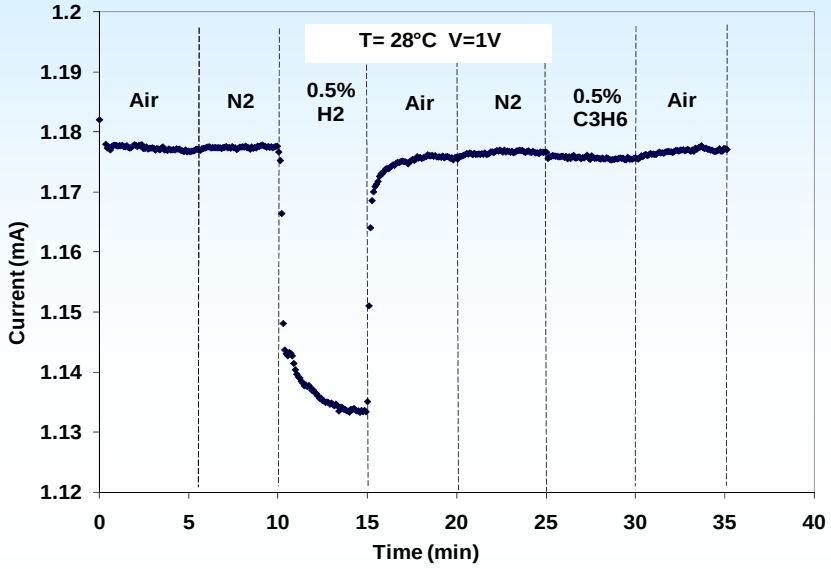
Aligned nanostructures with buried contacts



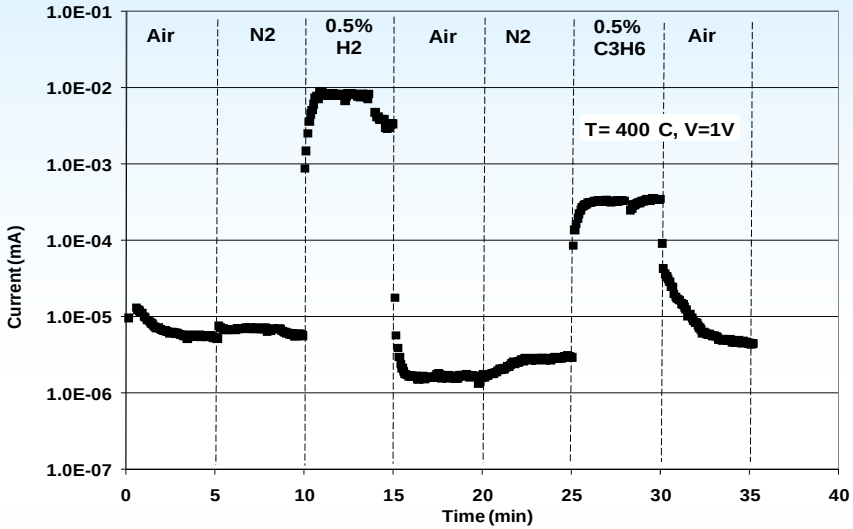
Processing approach

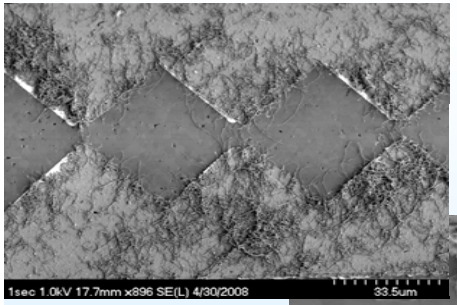
MICROFABRICATION APPLIED TO NANOTECHNOLOGY
Both Oxides and Carbon Demonstrated

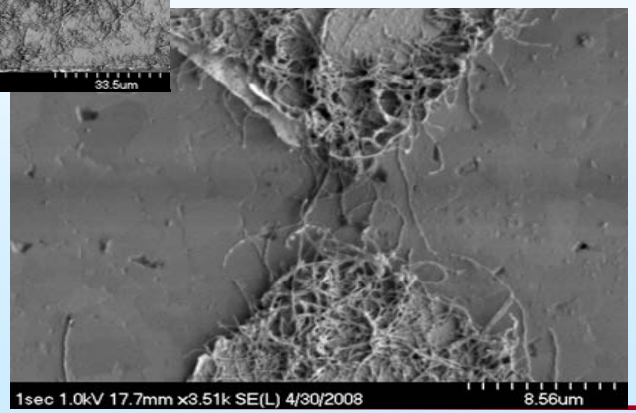
Carbon Nanotubes

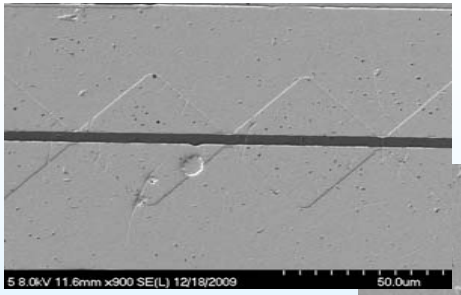


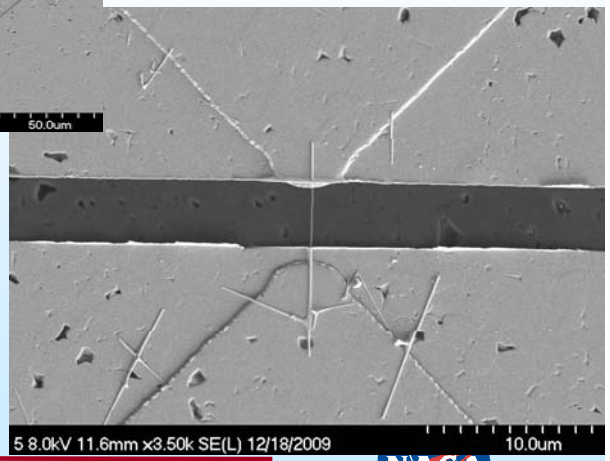
Tin Oxide Nanostuctures











SUMMARY

- AEROSPACE APPLICATIONS REQUIRE A RANGE OF SENSING TECHNOLOGIES
- A RANGE SENSOR AND SENSOR SYSTEM TECHNOLOGIES BEING USING:
  - MICROFABRICATION AND MICROMACHINING TECHNOLOGY
  - SMART SENSOR SYSTEMS
  - DRIVE SYSTEM INTELLIGENCE TO THE LOCAL (SENSOR) LEVEL
- HYDROGEN SENSOR TECHNOLOGY IN DEVELOPMENT FOR SIGNIFICANT TIME
- LEAK DETECTION SYSTEMS
  - "LICK AND STICK" WIRELESS PLATFORM
  - DISTRIBUTED SMART SENSOR SYSTEMS
  - MONITOR ACCUMULATON OF HAZARDOUS GASES
  - IDENTIFICATION AND ISOLATION OF LEAK LOCATIONS AND SUBSYSTEMS
  - FLIGHT READY HYDROGEN SENSOR SYSTEM AVAILABLE
- DEMONSTRATION IN A RANGE OF APPLICATIONS
  - MULTIPLE HYDROGEN SENSOR APPLICATIONS
  - FIRE DETECTION SYSTEM/ENGINE EMISSIONS MONITORING
- NANOTECHNOLOGY: EARLY STAGE OF DEVELOPMENT/ FULLY ENABLE "LICK AND STICK" SYSTEMS
- WORK FROM A CORE TECHNOLOGY BASE AND ADAPT THE SMART SENSOR SYSTEMS TO A RANGE OF APPLICATIONS