Microfabricated Chemical Sensors for Aerospace Fire Detection Applications

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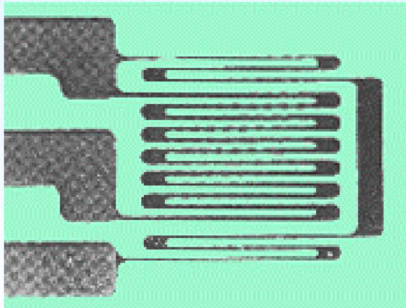
OUTLINE

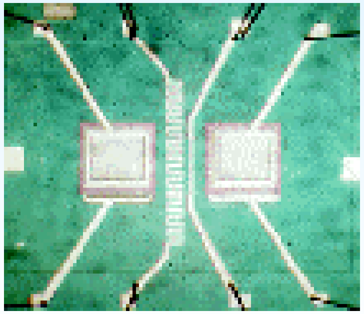
- INTRODUCTION
- MICROFABRICATED GAS SENSORS
- SENSOR DEVELOPMENT
    - HYDROGEN
    - CARBON MONOXIDE AND NITROGEN OXIDES
    - CARBON DIOXIDE
    - OXYGEN
    - HYDROCARBONS
- HIGH TEMPERATURE ELECTRONIC NOSE
- FIRE DETECTION NEEDS AND APPROACH
- SUMMARY AND FUTURE PLANS

SENSORS & ELECTRONICS TECHNOLOGY BRANCH

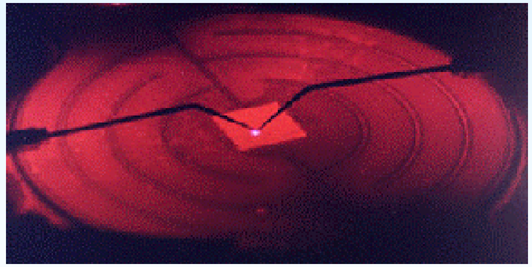
SCOPE OF WORK



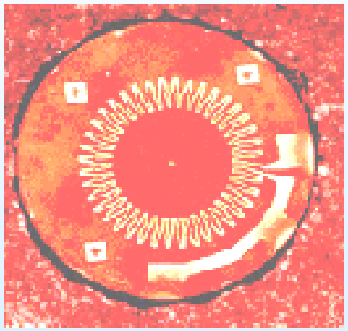
STRAIN GAGES



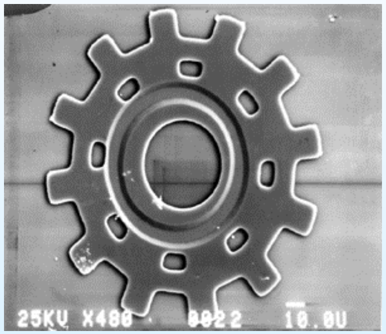
CHEMICAL SENSORS



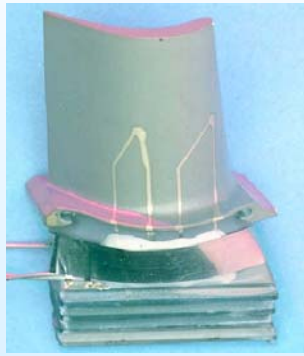
SILICON CARBIDE HIGH TEMPERATURE ELECTRONICS



HEAT FLUX GAGES



MICROELECTROMECHANICAL SYSTEMS (MEMS)



TEMPERATURE SENSORS

MICROSYSTEMS

MEMS: Micro ElectroMechanical Systems (Sensors, Electronics, and Actuators

MICROSYSTEMS: Sensors and devices created using microfabrication and micromachining techniques (Silicon electronics based processing)

BENEFITS: Reduced Size, Weight, and Power Consumption of Components With Significantly Increase Capabilities

APPLICATIONS

Smart Engine Control (e.g. noise, stall)
Emissions Reduction
Engine Tests
Structure and Material Development

Safety/Ice Detection
Health Monitoring
CFD Code Validation
Fuel Delivery (Atomizers)

ACTIVITIES

High Temperature Pressure Sensor
Emission Sensors
Heat Flux Sensor Array

Sheer Stress Sensor
Thin Film Senors
High Temperature Electronics

TECHNICAL CHALLENGES

Packaging
Material Stability, Compatibility

System Integration
Corresponding Actuator Systems

MICROFABRICATION AND MICROMACHINING TECHNOLOGY

MEMS-BASED TECHNOLOGY

- MICROELECTRONIC FABRICATION TECHNIQUES APPLIED TO CHEMICAL SENSOR DEVELOPMENT

  PHOTOLITHOGRAPHIC REDUCTION

  THICK AND THIN FILM METALLIZATION

  SPUTTERING AND ELECTRON-BEAM DEPOSITION

  BATCH PROCESSING/MINIMAL COST

  PRECISE CONTROL OF STRUCTURE

  MINIMAL SIZE, WEIGHT, AND POWER CONSUMPTION

- MICROMACHINING FOR THREE DIMENSIONAL STRUCTURES

  ETCHING AND SACRIFICIAL LAYER METHODS (MINIMIZE HEAT CONSUMPTION)

  FABRICATE COMPLEX SHAPES

  TAILOR SENSOR STRUCTURE

MICROFABRICATED GAS SENSORS

- COLLABORATIVE EFFORT BETWEEN NASA GRC AND CASE WESTERN RESERVE UNIVERSITY

- SENSOR DEVELOPMENT RESULTING FROM:
  - IMPROVEMENTS IN MICROFABRICATION AND MICROMACHINING TECHNOLOGY
  - 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

  - HYDROCARBONS (C_xH_y)
  - NITROGEN OXIDES (NO_X) AND CARBON MONOXIDE (CO)
  - OXYGEN (O_2)
  - CARBON DIOXIDE (CO_2)
  - HYDROGEN (H_2)

CHEMICAL SENSOR APPLICATION DEVELOPMENT AREAS

SAFETY

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.

LEAK DETECTION

DETECTION OF FUEL AND OXYGEN LEAKS FOR SPACE TRANSPORTATION APPLICATIONS SUCH AS SPACE SHUTTLE, X-33 AND BANTAM. WIDE RANGE DETECTION IN INERT ENVIRONMENTS AND POSSIBLY CRYOGENIC CONDITIONS.

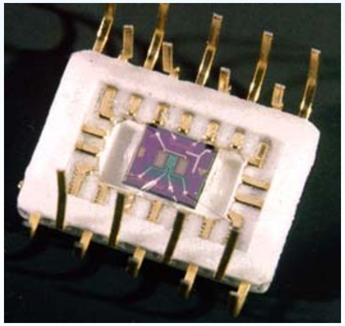
EMISSIONS

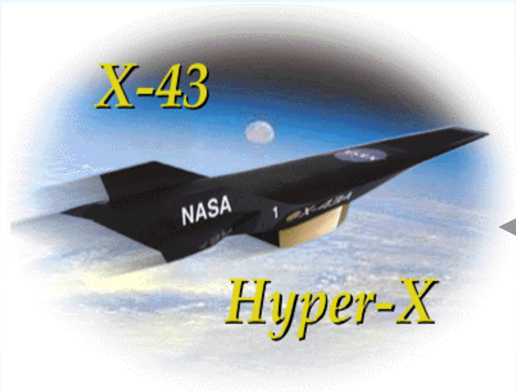
DETECTION OF HYDROCARBONS, NOx, CO, ETC. FOR HEALTH MONITORING AND ACTIVE COMBUSTION CONTROL APPLICATIONS. SENSITIVE DETECTION IN HIGH TEMPERATURE HARSH ENVIRONMENTS IN THE PRESENCE OF A NUMBER OF INTERFERING GASES.

HYDROGEN LEAK SENSOR TECHNOLOGY

1995 R&D 100 AWARD WINNER

- MICROFABRICATED USING MEMS-BASED TECHNOLOGY FOR MINIMAL SIZE, WEIGHT AND POWER CONSUMPTION
- HIGHLY SENSITIVE IN INERT OR OXYGEN-BEARING ENVIRONMENTS, WIDE CONCENTRATION RANGE DETECTION
- INTEGRATED WITH SMART ELECTRONICS FOR SIGNAL PROCESSING AND TEMPERATURE CONTROL





SYTEM DELIVERED FOR HYPER X FLIGHT PLANNED FOR SUMMER 00

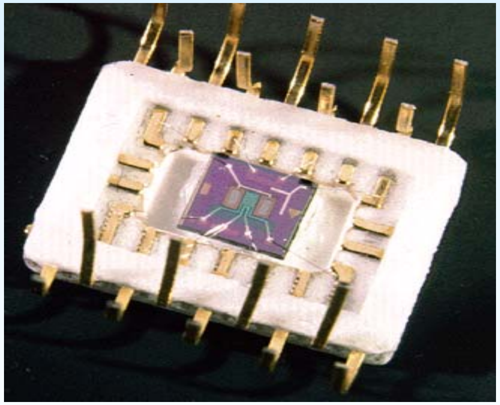
DEMONSTRATED ON STS-95 and STS-96 SHUTTLE MISSIONS

20 SENSOR SYSTEM DELIVERED FOR X-33 SAFETY SYSTEM

AUTOMATED HYDROGEN LEAK DETECTION SYSTEM ONNATURAL GAS POWERED CROWN VICTORIA ASSEMBLY LINE

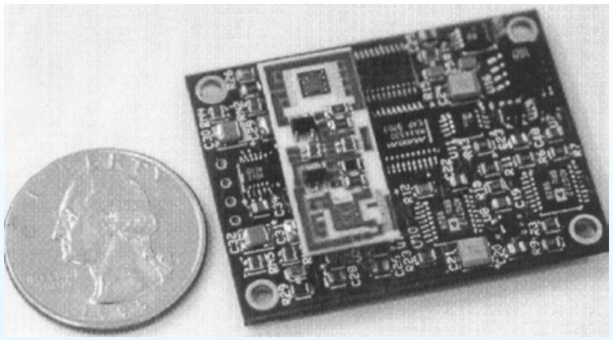
CHOSEN FOR INCLUSION ON ISS WATER PROCESSING O2 GENERATOR.

MINIATURIZED SMART LEAK SENSOR SYSTEM



MICROFABRICATED HYDROGEN SENSOR

HYDROGEN SENSORS ON SPACE SHUTTLE

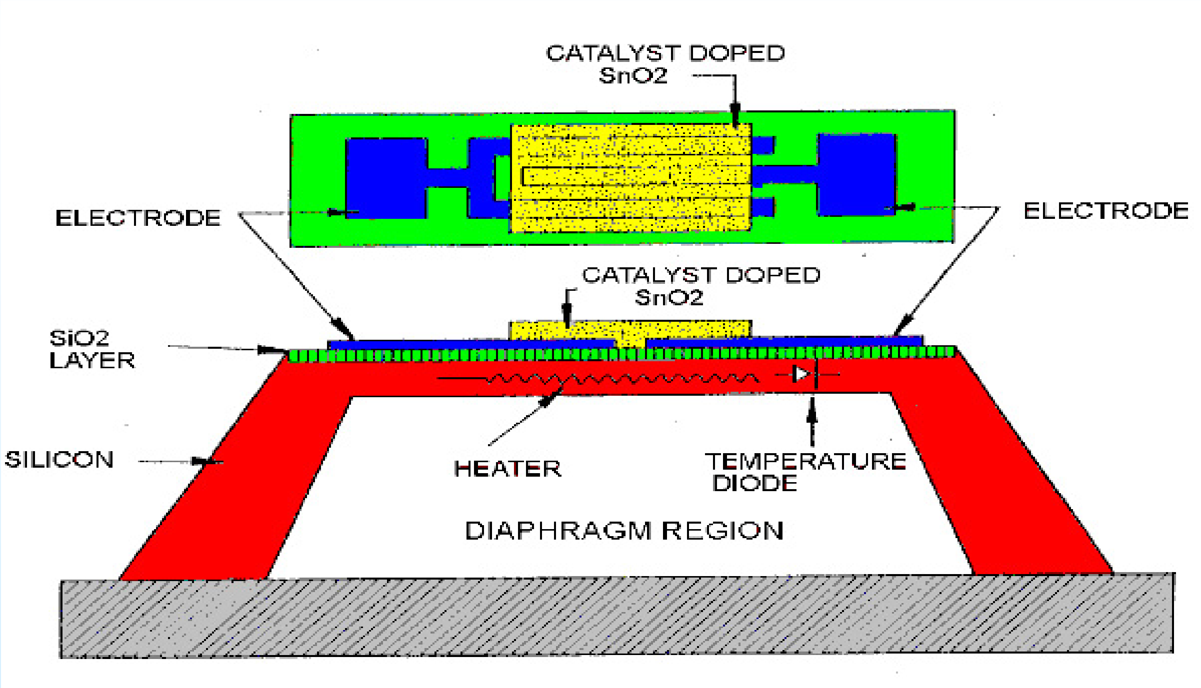


PROTOTYPE HYDROGEN/OXYGEN SENSOR SYSTEM WITH ELECTRONICS

DEMONSTRATE STAND-ALONE SMART LEAK DETECTION SYSTEM WITH A SURFACE AREA THE SIZE OF POSTAGE STAMP

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



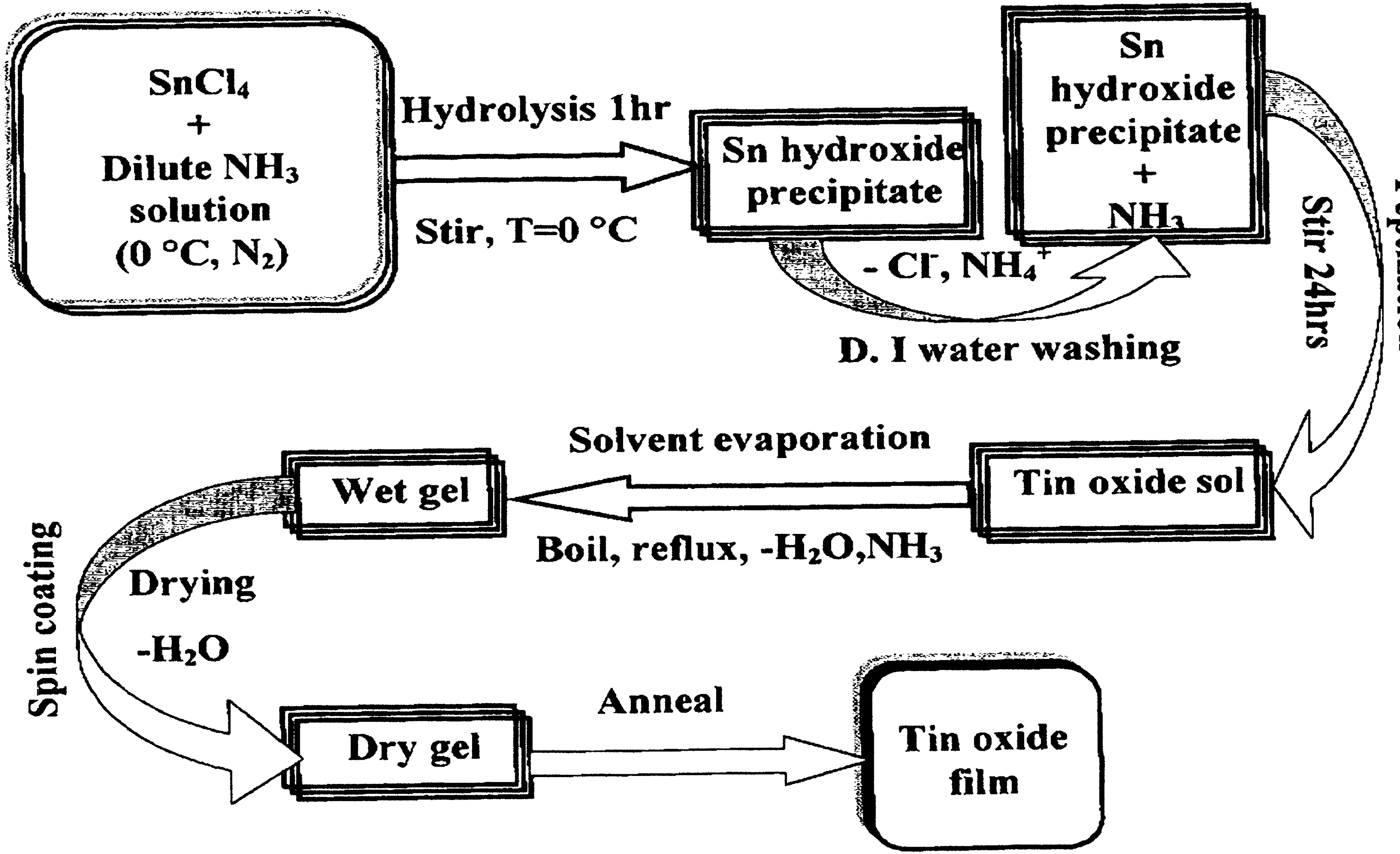
STRUCTURE OF A MICROFABRICATED TIN-OXIDE SENSOR

PROPERTIES OF NANOCRYSTALLINE SNO2 THIN FILM FROM SOL-GEL PROCESS

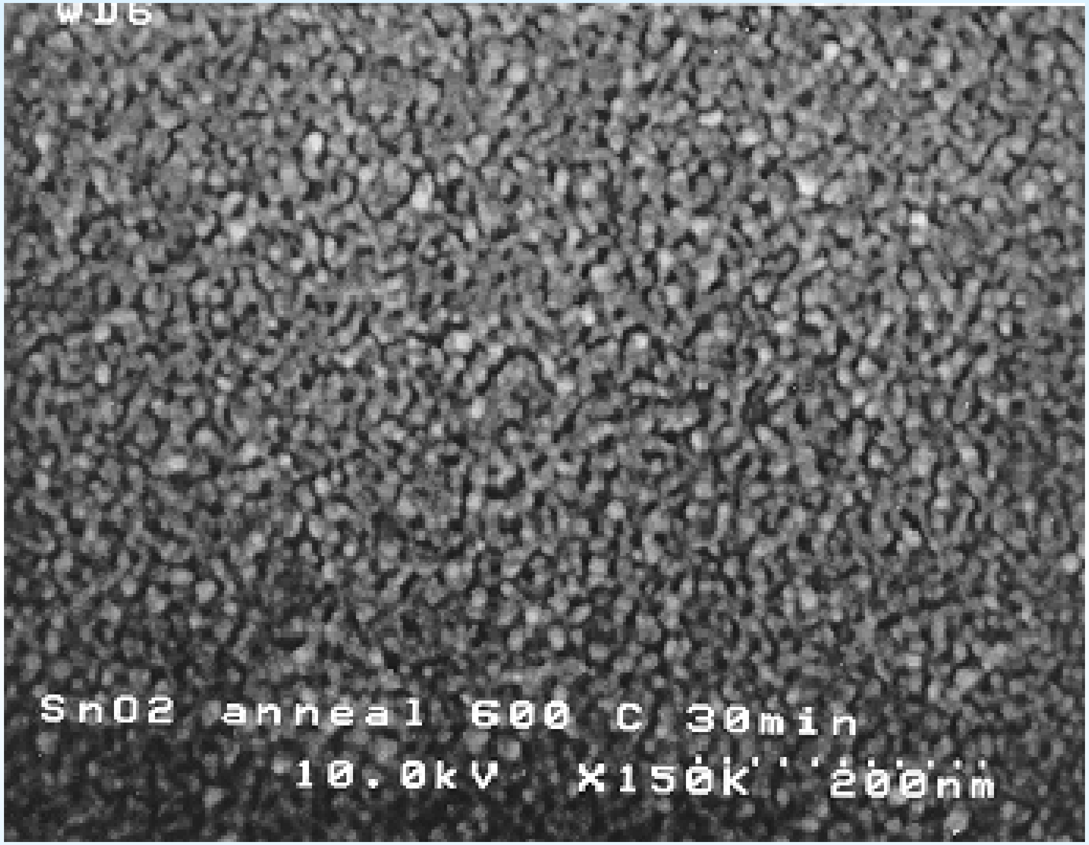
- SMALL PARTICLE SIZE
- HIGH POROSITY
- LARGE SURFACE AREA
- HOMOGENEOUS CHEMICAL AND PHYSICAL STRUCTURE
- DIFFERENT ANNEALING MECHANISMS/RATES

ADVANTAGES FOR SENSOR APPLICATIONS

- HIGH SENSITIVITY
- FAST RESPONSE
- STABLE OPERATION
- LOWER TEMEPERATURE OPERATION

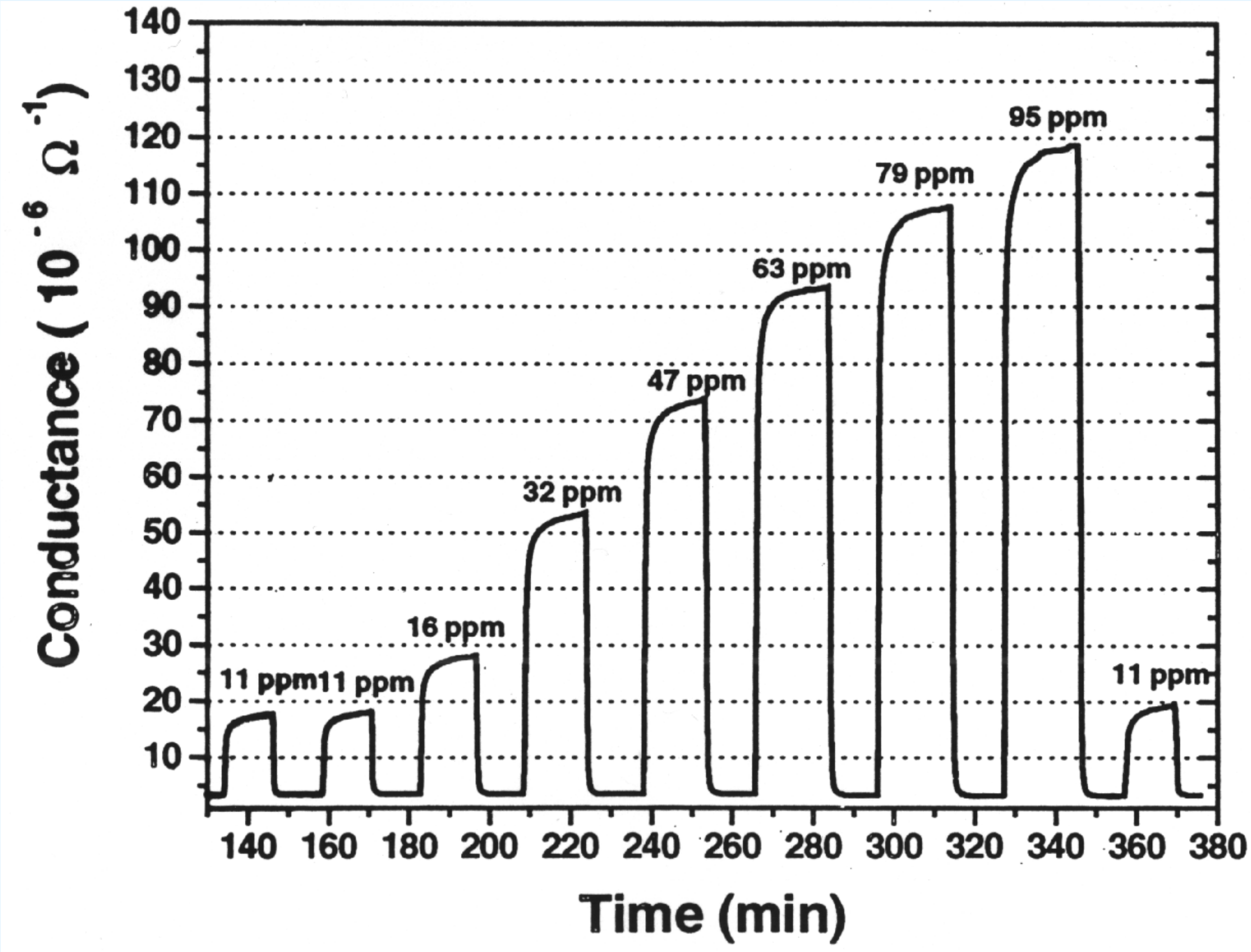


Sol-Gel Process For To Produce Stable Nanocrystalline Thin Films

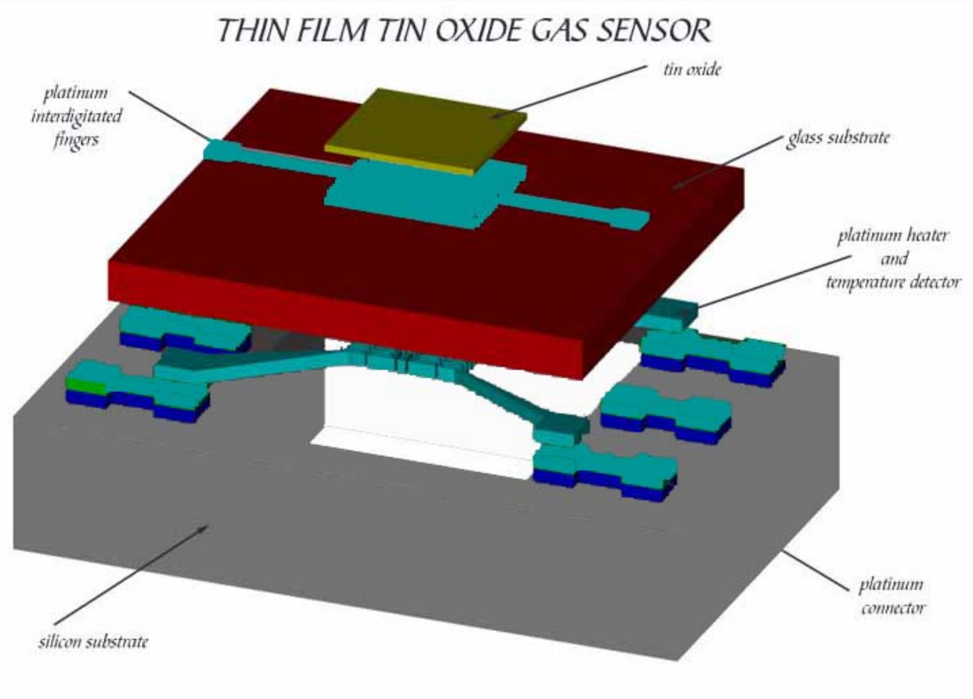


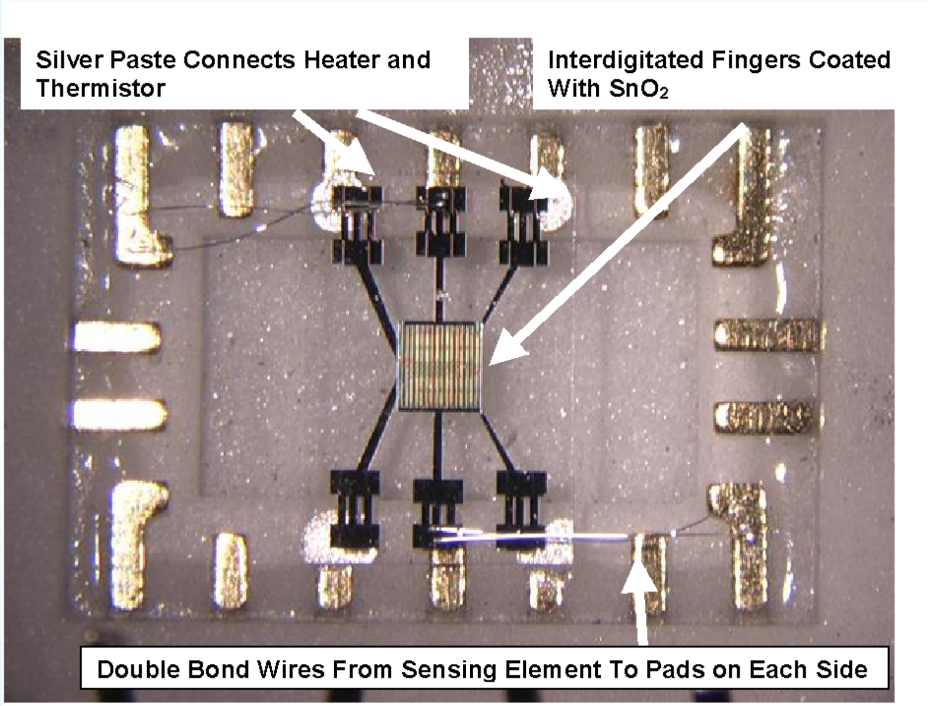
Nanocrystalline SnO_2 after annealing at 600°C for 30 minutes.

Response of a Pt-doped Tin-oxide Sensor to a Range of CO Concentrations at 300˚C in Air.



STRUCTURE OF A SnO_2 BASED SENSOR ON A Si SUBSTRATE

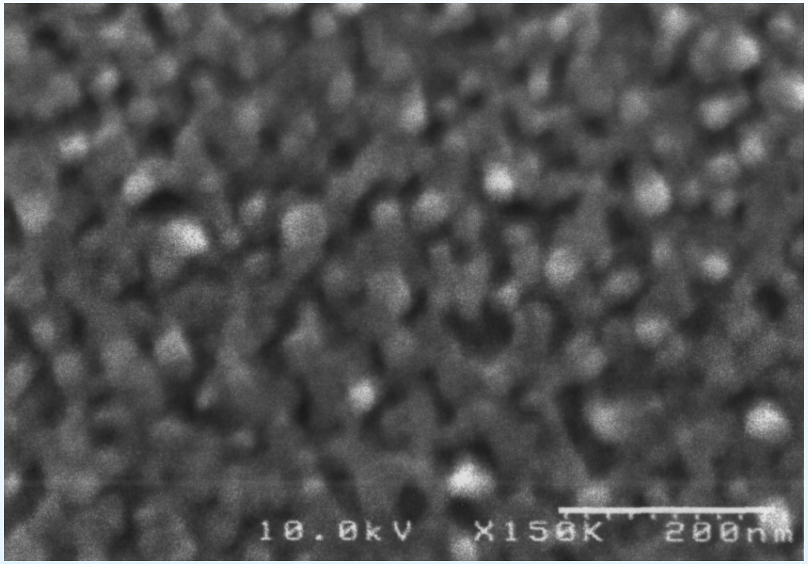




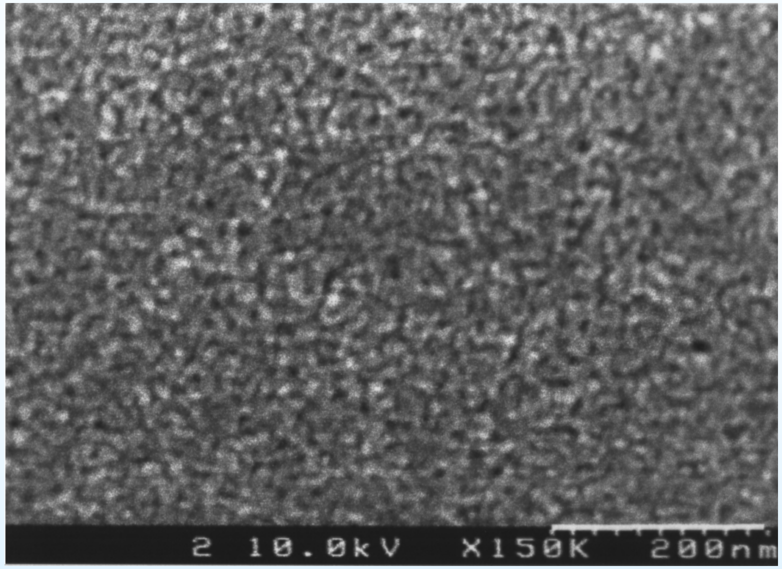
EFFECT OF CALCINATION TIME AND SILICATE

700C calcined for 24 hours (on silicon substrate)

Undoped SnO_2 Film



5 wt% SiO_2 dopedSnO_2 Film



The particle and pore sizes increase with calcination time
Silicate doping inhibits the particle growth

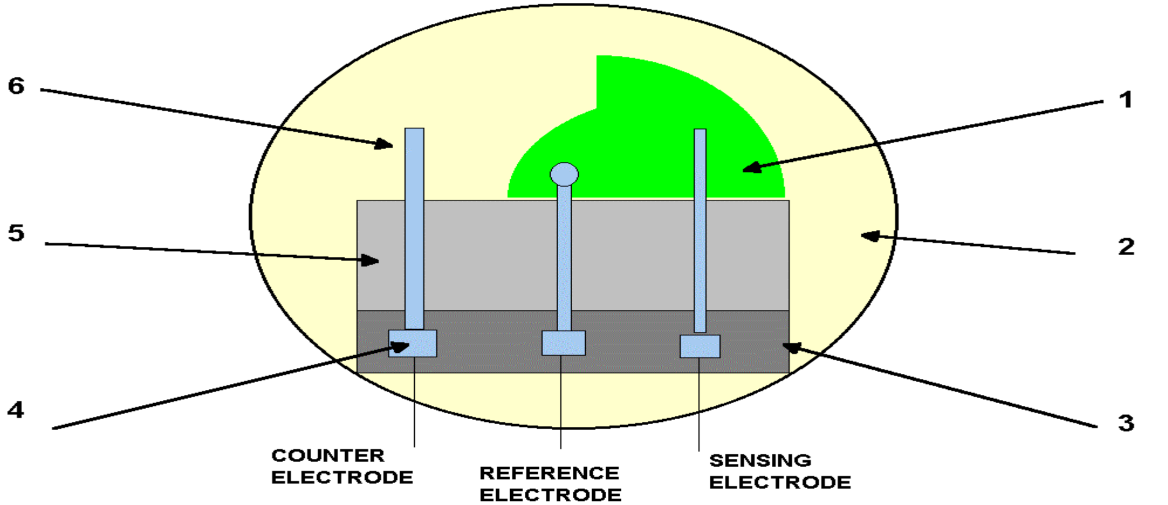
MICROFABRICATED NASICON BASED CO2 SENSOR TECHNOLOGY

• MICROFABRICATED FOR MINIMAL SIZE, WEIGHT AND POWER CONSUMPTION

• ELECTROCHEMICAL CELL DESIGN USING PROTON CONDUCTING NASICON AS ELECTROLYTE TO DETECT A RANGE OF CO2 CONCENTRATIONS

• TEMPERATURE DETECTOR AND HEATER TO BE INCORPORATED INTO SENSOR STRUCTURE

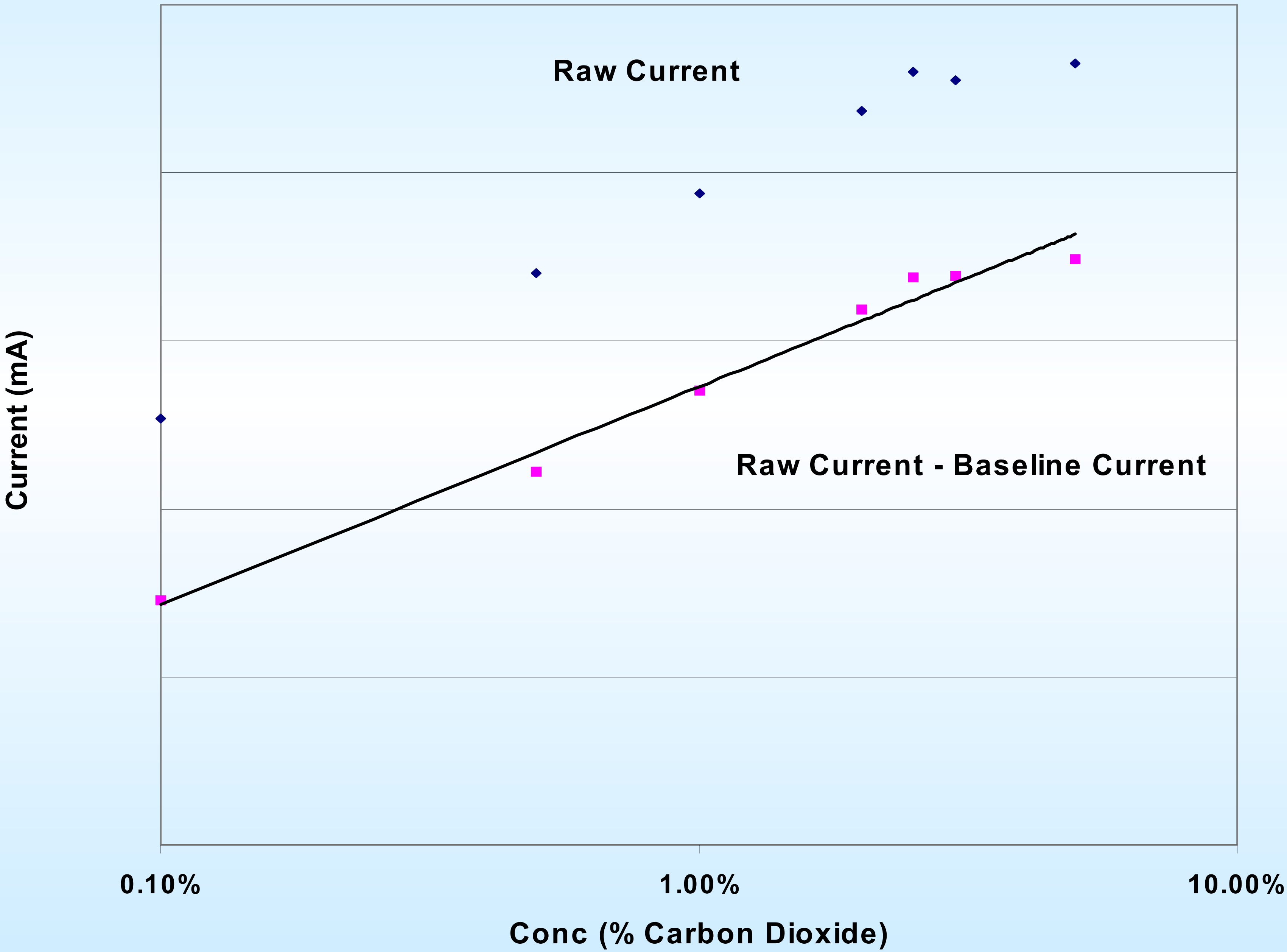
• SENSOR TO BE COMBINED WITH CO SENSOR FOR SIMULTANEOUS CO/CO2 DETECTION



1. THICK FILM CARBONATE
2. NASICON BASE
3. INSULATING ADHESIVE
4. BONDING PAD, CONDUCTING ADHESIVE
5. THICK FILM INSULATION
6. THICK FILM PLATINUM ELECTRODE

STRUCTURE OF A NASICON-BASED ELECTROCHEMICAL CELL CO2 SENSOR

CO2 Sensor Response- Peak Currents
3 min set delay - 2 min exposure delay



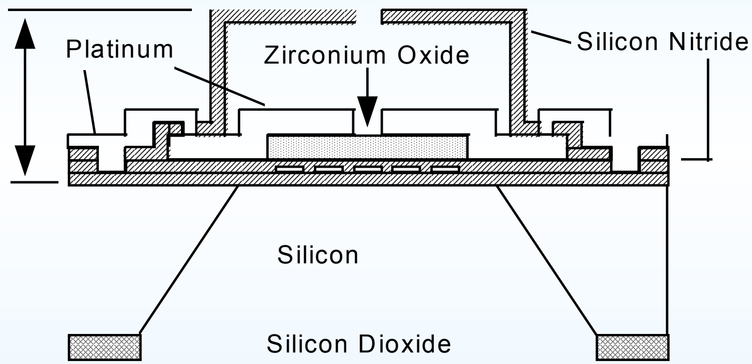
MICROFABRICATED OXYGEN SENSOR TECHNOLOGY

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

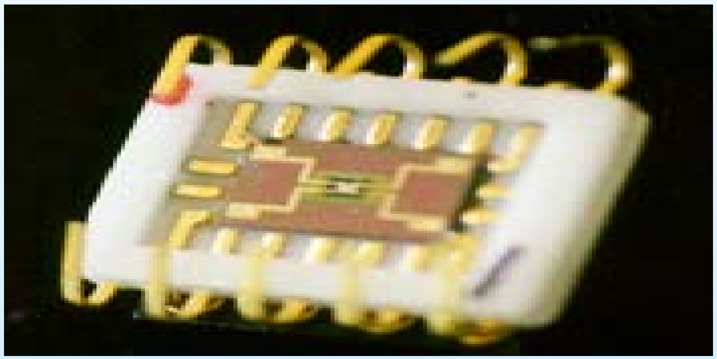
- **AMPEROMETRIC OPERATION ALLOWS MEASUREMENT OF OXYGEN OVER A WIDE CONCENTRATION RANGE (0-100%)**

- **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

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

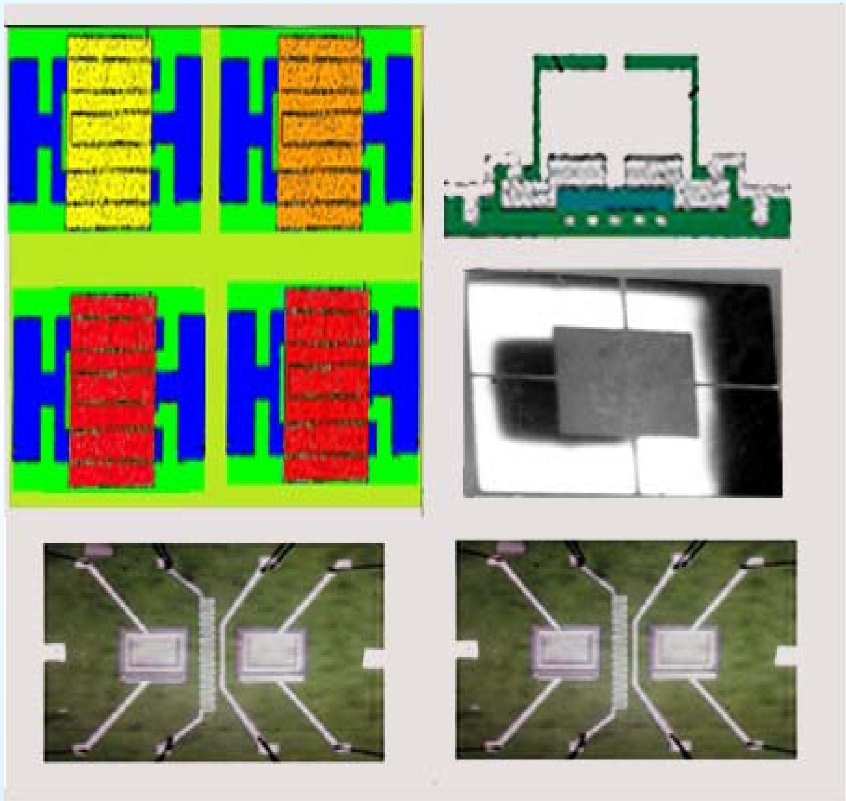
HIGH TEMPERATURE GAS SENSOR ARRAY
HIGH TEMPEERATURE ELECTRONIC NOSE

SnO_2 Resistor

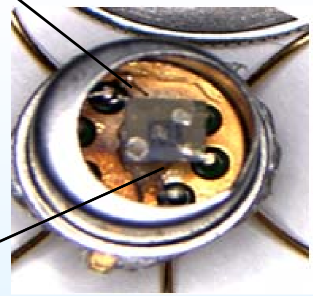
TiO_2 Resistor

Electrochemical Oxygen Sensor

Selectively Filtered SnO_2 Resistors



SiC-Based Pressure Sensor

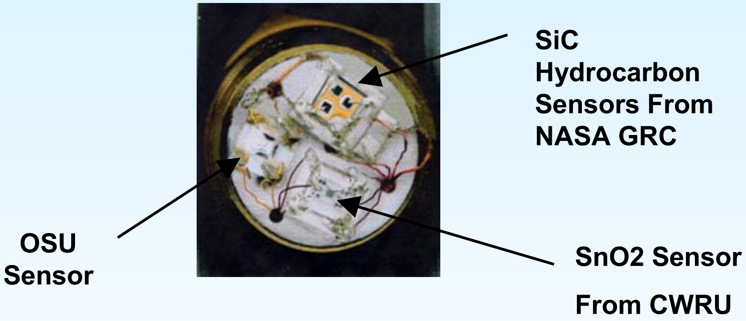


Metal-SiC Schottky diodes

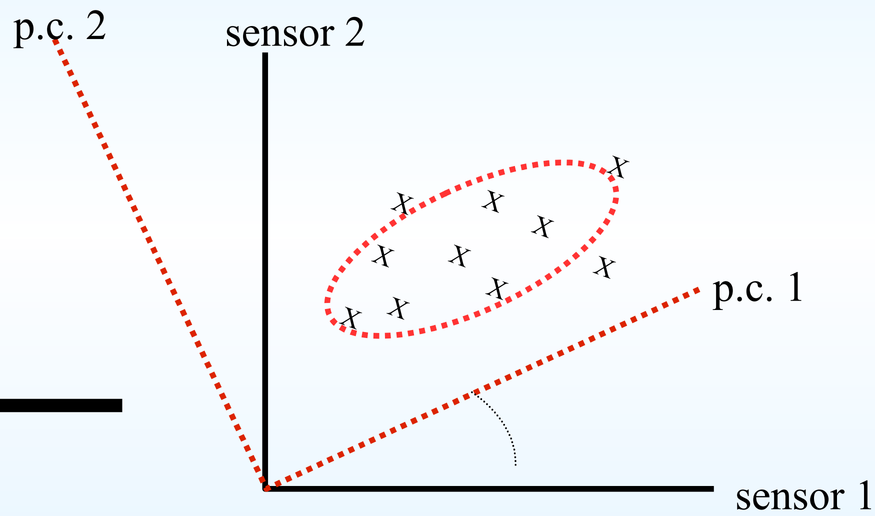
Metal-Reactive Insulator SiC Schottky diodes

SOFTWARE DEVELOPMENT TO INTERPRET SIGNALS
PROTOTYPE SOFTWARE SYSTEM IMPLEMENTED

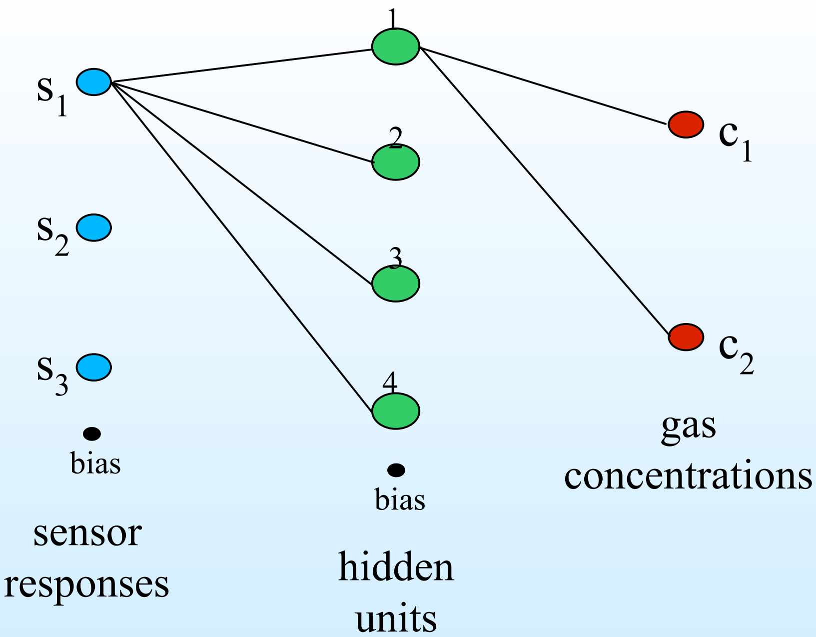
Prototype Sensor Head Used in Engine Test



BREAKING THE DATA SET DOWN INTO PRINCIPLE COMPONENTS HELPS DATA ANALYSIS. VERY DIFFERENT TYPES OF SENSORS AS USED IN THIS APPROACH IMPROVES THE CAPABILITIES OF THIS TECHNIQUE

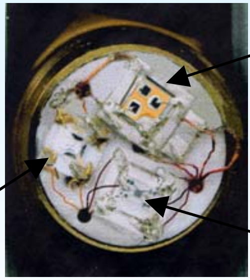


GOAL: USE VERY DIFFERENT SENSORS IN AN ARRAY TO PROVIDE INFORMATION ON THE ENVIRONMENT



FOR A GIVEN SET OF SENSOR RESPONSES, THE TRAINED NETWORK PREDICTS THE COMPONENT CONCENTRATIONS OF AN UNKNOWN MIXTURE OF, E.G. CO AND CH_4

Brassboard Integrated Microsystem

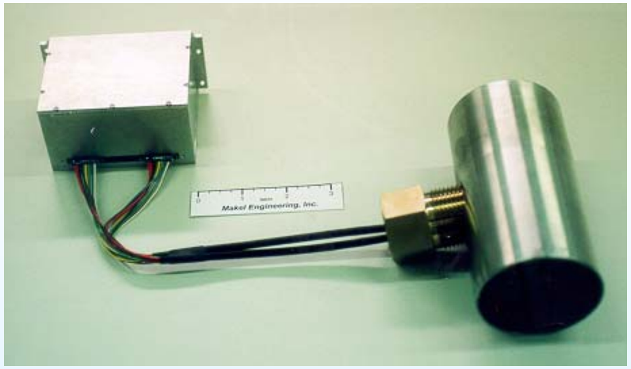


SiC Hydrocarbon Sensors From NASA GRC

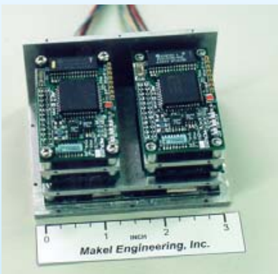
OSU Sensor

SnO2 Sensor From CWRU

Prototype Sensor Head



Electronics and Sensor Head



Sensor Operating Temperature 400 C with +/- 8 C stability in dynamic environment

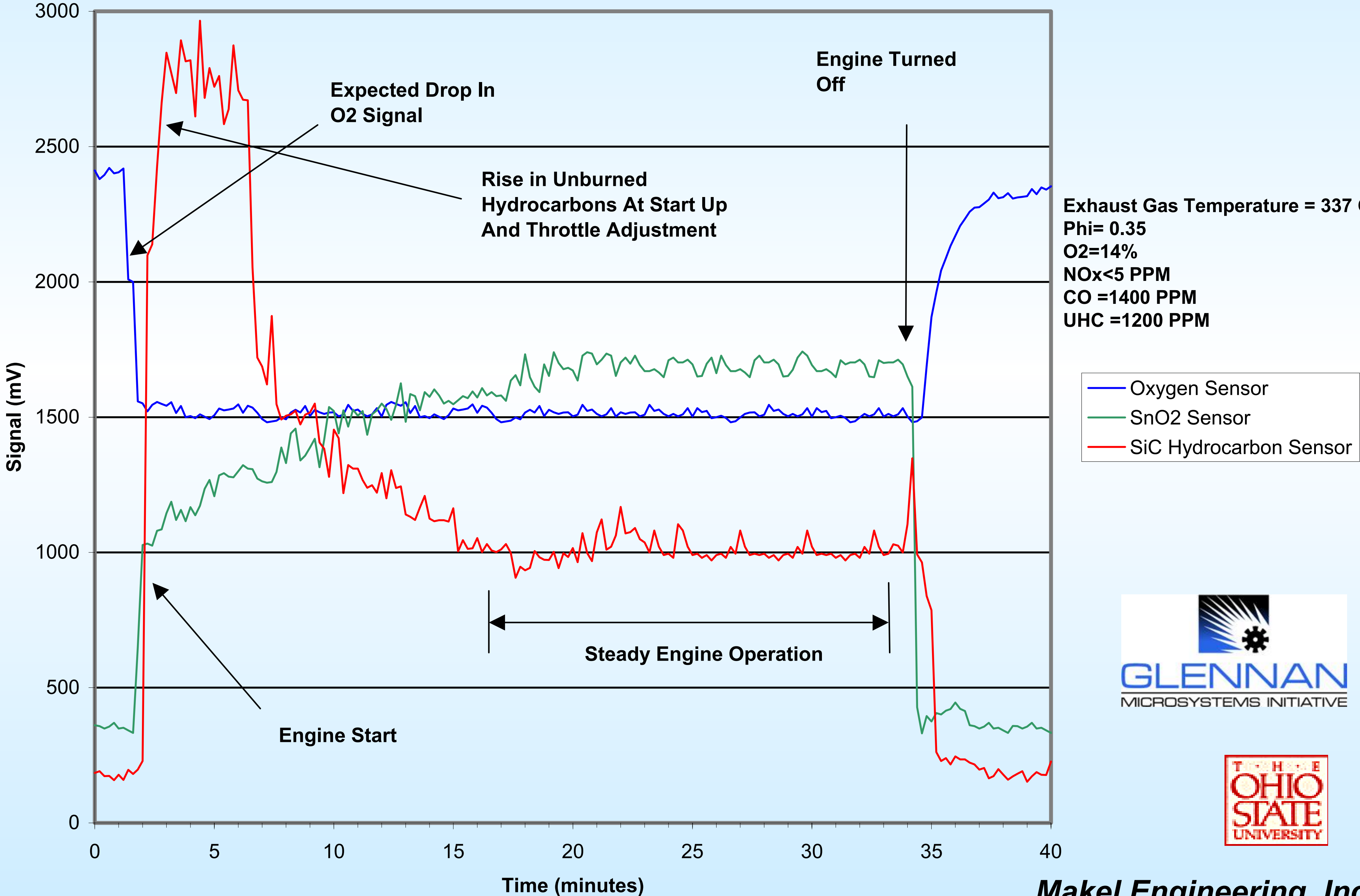
Sensors Tested

- Oxygen (0 to 21%)
- CO (0 to 3000 PPM)
- Hydrocarbons (0 to 2500 PPM C_2H_2)
- NOx (0 - 300 PPM)

Instrumentation & Control Technology Division

Harsh Environment Demonstration Testing

1.9 liter, four cylinder HCCI at U.C. Berkeley (propane/air)



Makel Engineering, Inc

Micro-Fabricated Gas Sensors for Low False Alarms

BACKGROUND

- COMMERCIAL PASSENGER AIRCRAFT TO HAVE CARGO SMOKE DETECTION & FIRE SUPPRESSION
- EXISTING SMOKE DETECTION TECHNOLOGY PRONE TO FALSE ALARMS (DIRT, DUST, MOISTURE, GASES, ETC.)
  - EMERGENCY DIVERSIONS & UNNECESSARY DISCHARGE OF HALON
  - FALSE ALARM RATE AS HIGH AS 200:1
- PRODUCE TECHNOLOGY WITH DIFFERENT FAILURE MECHANISMS
  - MONITOR CHEMICAL SPECIES
  - COMPLEMENTARY INFORMATION
- A NUMBER OF GASES EMITTED DURING FIRE/DEPENDENT ON FIRE
  - TWO GASES OF PARTICULAR INTEREST: CO/CO2
- IN COLLABORATION WITH:
  - FAA: TESTING
  - SANDIA NATIONAL LABS: MODELING

Micro-Fabricated Gas Sensors for Low False Alarms

FEATURES

•MICROFABRICATED CO/CO_2 GAS SENSOR ARRAY

➢CENTRAL TO APPROACH

➢NANOCRYSTALLINE MATERIALS (IN CO SENSOR) PRODUCE MORE SENSITIVE, STABLE SENSORS

➢TWO APPROACHES TO CO2 DETECTION

➢MINIMAL SIZE/WEIGHT/POWER

•CHEMICAL GAS SENSORS PROVIDE GASEOUS PRODUCT-OF-COMBUSTION INFORMATION

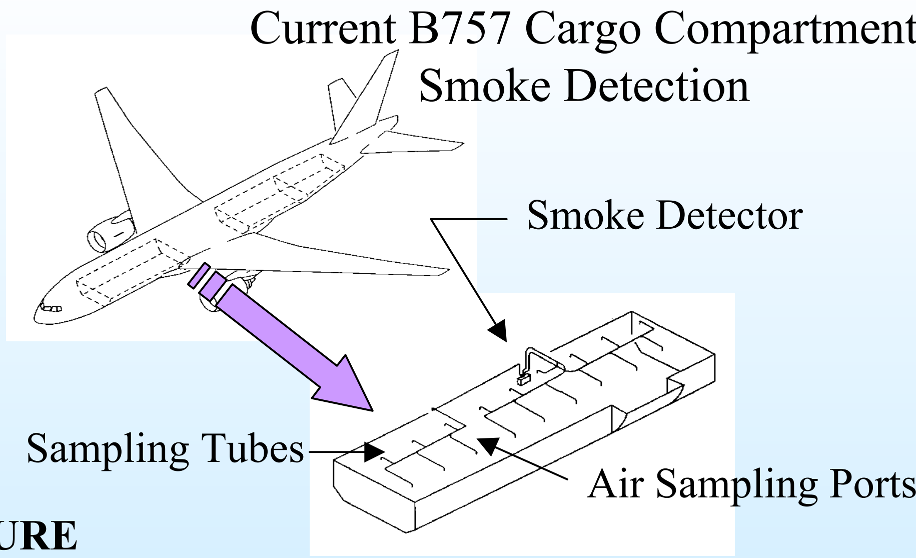
➢SENSOR ARRAY CAN DETECT RANGE OF GAS SPECIES

➢TO BE COMBINED WITH INTELLIGENT SOFTWARE FOR PATTERN RECOGNITION

•BENEFITS

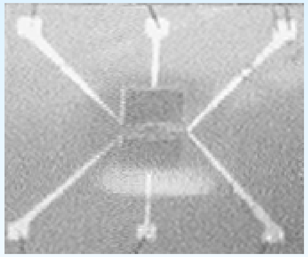
➢DISCRIMINATE FIRES FROM NON-FIRES

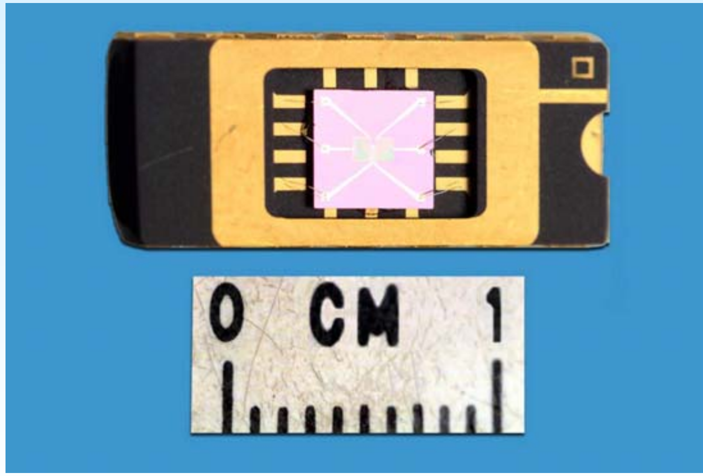
➢POTENTIAL SPIN-OFF TO HIGH-TEMPERATURE ENGINE MULTI SPECIES EMISSION CONTROL



CHEMICAL SENSOR FIRE DETECTION

CO/CO2 SENSOR ON A CHIP

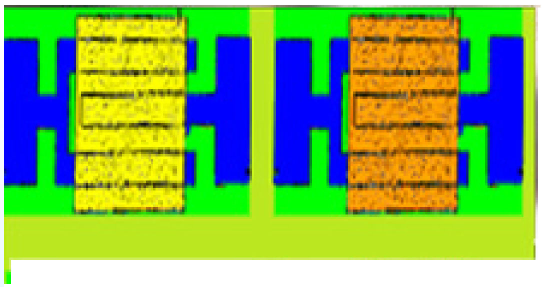


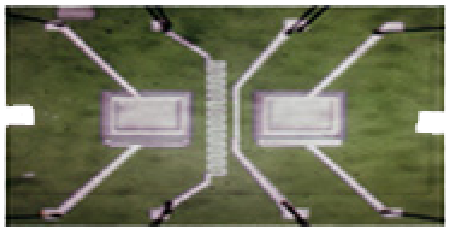


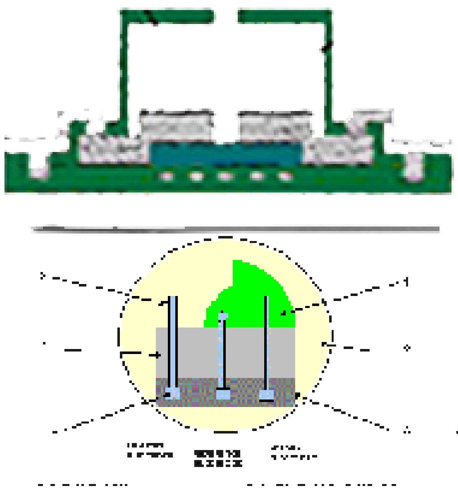
SnO2 Resistor (CO)

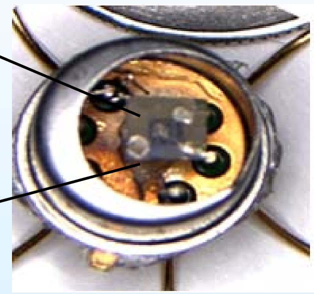
SnO2 Resistor (CO2)

Electrochemical Oxygen Sensors (O2 and Humidity)









Metal-SiC Schottky diodes

NASICON Based Electrochemical Cell

CONFIGURATION OF POTENTIAL FIRE DETECTION ARRAY

Makel Engineering, Inc.

SUMMARY (CONT)

- AEROSPACE APPLICATIONS REQUIRE A RANGE OF CHEMICAL SENSING TECHNOLOGIES

- NEW FAMILY OF GAS SENSOR TECHNOLOGY BEING DEVELOPED TO MEET THESE NEEDS USING:
  - MICROFABRICATION AND MIRCROMACHING TECHNOLOGY
  - NANOMATERIALS
  - SiC-BASED SEMICONDUCTOR TECHNOLOGY

- FIRE DETECTION APPLICATIONS:
  - LEVERAGE EXISTING SENSOR DEVELOPMENT
    - MULTIPLE SENSOR TYPES
    - SENSOR ARRAYS
    - ELECTRONICS
  - MINIATURIZED TECHNOLOGY WITH MINIMAL SIZE, WEIGHT, AND POWER CONSUMPTION
  - MULTIPLE POINT LOCATION

SUMMARY

- COMBINATION OF SMOKE AND CHEMICAL SENSING TECHNOLOGY
  - COMPLEMENTARY INFORMATION
  - DIFFERING FAILURE MECHANISMS

- MULTIFUNCTIONAL SENSOR ARRAY
  - CO/C02/HUMIDITY/HYDROCARBONS
  - INTEGRATED SYSTEM
  - SENSORS/POWER/COMMUNICATION

- FIRST GENERATION SYSTEM TO BE TESTED AT FAA IN FALL O1

- SANDIA MODELING: SENSOR PLACEMENT/INTERPRETATION OF RESULTS

- SYNERGY BETWEEN NASA SPACE AND AERONAUTICS APPLICATIONS

- LONG-TERM: INTEGRATE WITH MEMS-BASED SMOKE DETECTION SYSTEM FOR SPACE APPLICATIONS