DEVELOPMENT AND APPLICATION OF HIGH TEMPERATURE SENSORS AND ELECTONICS

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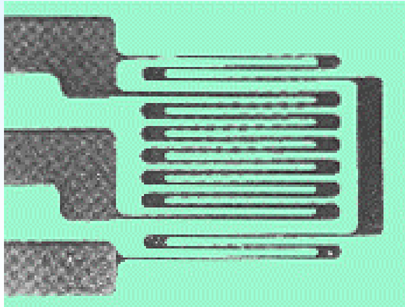
OUTLINE

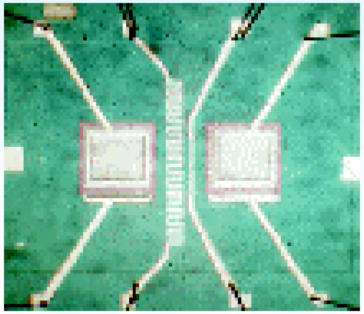
- INTRODUCTION
- PHYSICAL SENSOR TECHNOLOGY
  - THIN FILM SENSORS
  - LEAD WIRES
- SiC HIGH TEMPERATURE ELECTRONICS/SENSORS
  - PRESSURE SENSOR
- CHEMICAL SENSOR TECHNOLOGY
  - TIN-OXIDE BASED GAS SENSORS
  - HIGH TEMPERATURE ELECTRONIC NOSE
- SUMMARY/COMMON THEMES

SENSORS & ELECTRONICS TECHNOLOGY BRANCH

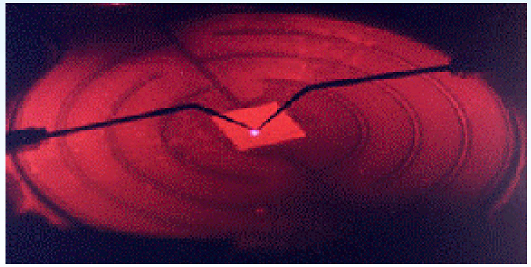
SCOPE OF WORK



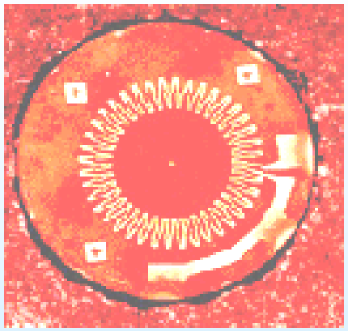
STRAIN GAGES



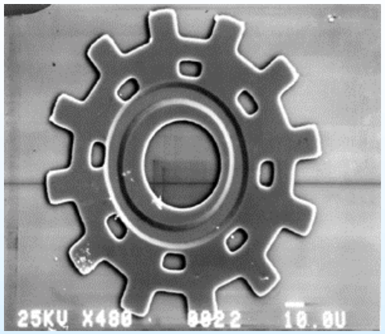
CHEMICAL SENSORS



SILICON CARBIDE HIGH TEMPERATURE ELECTRONICS



HEAT FLUX GAGES



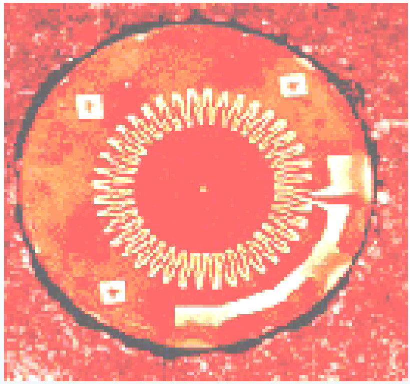
MICROELECTROMECHANICAL SYSTEMS (MEMS)

TEMPERATURE SENSORS

THIN FILM SENSOR TECHNOLOGY

- VERY THIN, MINIMALLY INTRUSIVE SENSORS ABLE TO PROVIDE HIGH TEMPERATURE DATA WITHOUT DISTURBING AIR FLOW
- CAN BE FABRICATED DIRECTLY ON CERAMIC AND METAL ENGINE PARTS WITHOUT THE NEED TO CUT INTO THE PART.
- CAN BE APPLIED TO METAL BASED MATERIALS, CERAMIC MATERIALS, AND CERAMIC MATRIX COMPOSITES.
- MULTIFUNTIONAL, INFORMATION RICH SENSORS CURRENTLY UNDER DEVELOPMENT

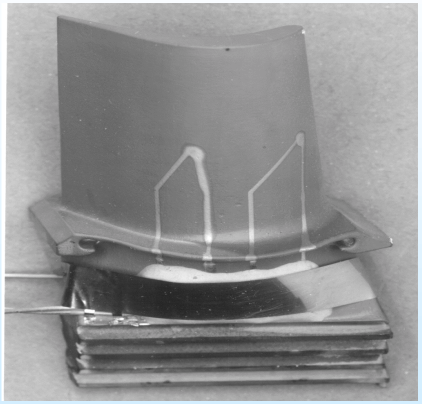
THIN FILM THERMOCOUPLES ON CERMIC MATRIX COMPOSITE HOOP



HEAT FLUX GAGE ON SILICON NITRIDE PLUG

1995 R&D 100 Award

PdCr THIN FILM GAUGE APPLIED ON ALLIED-SIGNAL ENGINES CERAMIC TURBINE BLADE



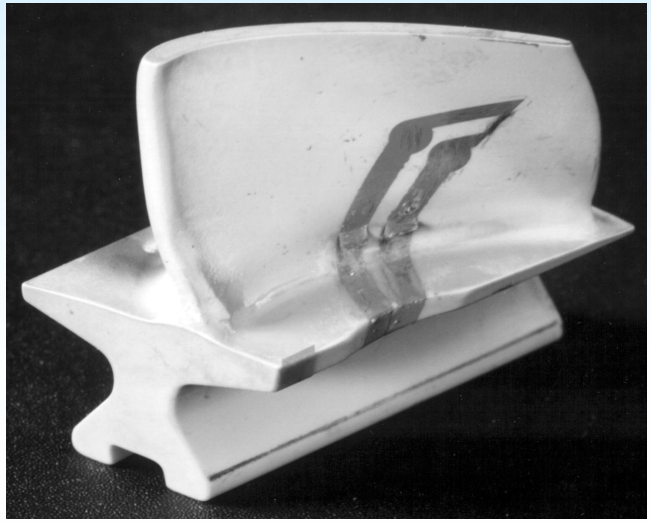
THIN FILM THERMOCOUPLES ON SPACE SHUTTLE MAIN ENGINE TURBINE BLADES

HIGH TEMPERATURE STRAIN SENSOR TECHNOLOGY

1991 R&D 100 Award

PdCr wire strain gauge applied on Ford Motor Co. exhaust manifold

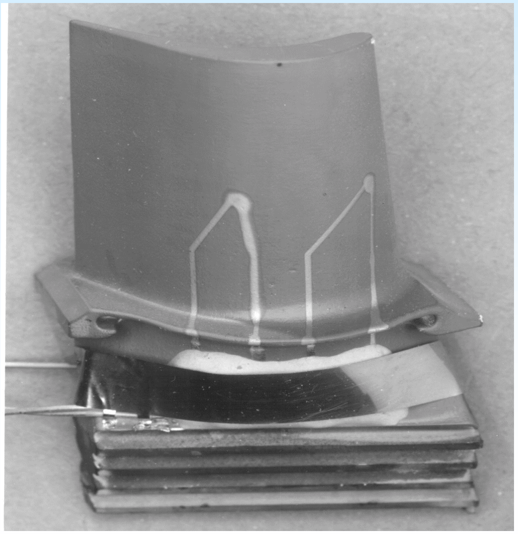
1995 R&D 100 Award

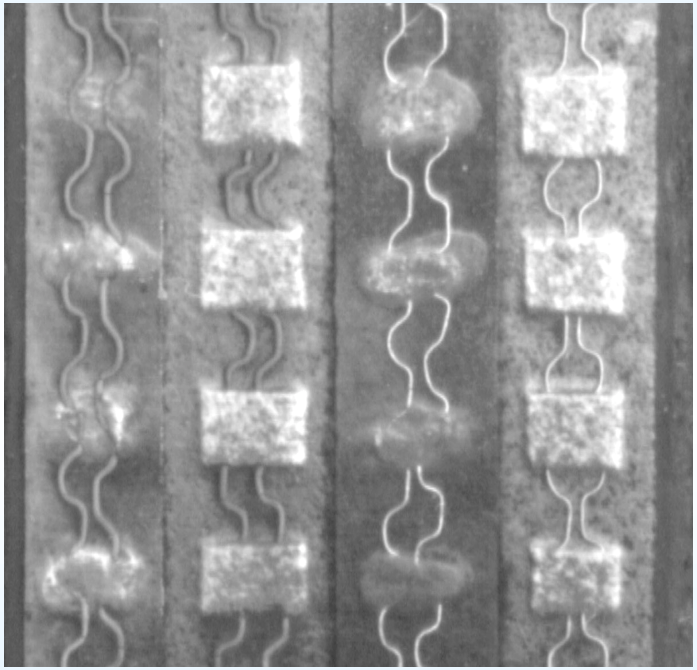


PdCr thin film gauge applied on Allied-Signal Engines ceramic turbine blade

- High temperature strain sensors developed based on a newly developed alloy, PdCr.
- Wire gauge operates to 800 °C and thin film gauge operates to 1100 °C, compared to 400°C of the commercially available technologies.
- Technology transferred to Pratt & Whitney, GEAE, AlliedSignal Engine, Allison, Ford Motor et al. for advanced materials and engine testing.
- Wire strain gauge technology commercialized.
- New ceramic gauge materials being explored for higher temperature applications.

LEAD WIRE CONNECTIONS SIGNIFICANT PROBLEM



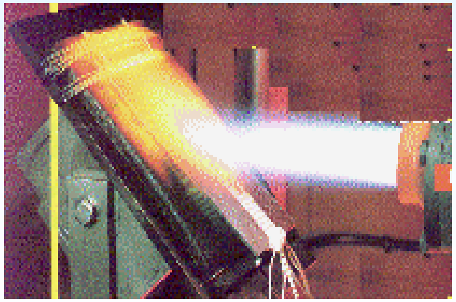


"CONVOLUTED" APPROACH

STANDARD APPROACH

Long-lived Convoluted Thermocouples For Ceramics Temperature Measurements 1998 R&D 100 Award

Sensor configuration



Burner rig evaluation

Applied to a GEAE IHPTET SiC/SiC combustor liner

Applied to a C/SiC cylinder

Unique convoluted design and installation technique successfully provided the needed thermal stress relief

Good adhesion on ceramic based materials such as ceramic matrix composite

Operating in a hostile environment (1300 C 4560 torrs) for a long period of time (>20 hrs)

A better, faster, cheaper enabling technology

Commercialized by HiTec Products Inc.

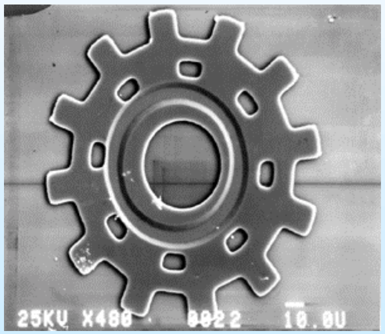
SiC-BASED MICROSYSTEMS

•SiC-based electronics and sensors can operate in hostile environments (600 C = 1112 F GLOWING RED HOT!) where conventional silicon-based electronics (limited to 350 C) cannot function.

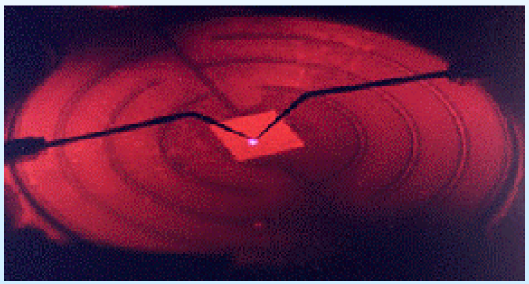
SiC-BASED MICROSYSTEM BENEFITS

- **Operation in High Temperatures, High Power, High Radiation, and Harsh Environments**
- **Reduced Size, Weight, and Power Consumption- Electronics in Harsh Environments**
- **Use Si Based Processing Techniques**

<u>INTEGRATED SYSTEMS FOR USE IN HARSH ENVIRONMENTS</u>



ACTUATORS



ELECTRONICS

SENSORS

SiC-BASED PRESSURE SENSORS

- SiC HAS EXCELLENT MECHANICAL PROPERTIES FOR USE AS A HARSH ENVIRONMENT PRESSURE SENSOR (T > 500 °C, SILICON UNDERGOES PLASTIC DEFORMATION)

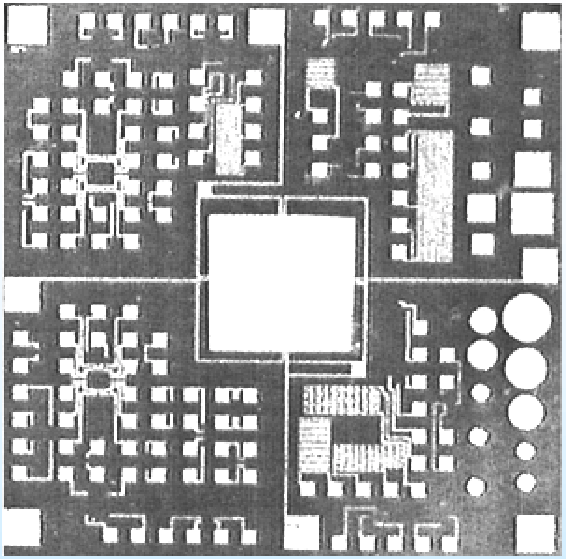
  STRONG MATERIAL
  LARGE PIEZORESISTIVE COEFFICIENTS

- FORM DIAPHRAM OF SiC AND INTEGRATE WITH ELECTRONICS

- WIDE RANGE OF APPLICATIONS

  AERONAUTIC ENGINE APPLICATIONS
  AUTOMOTIVE APPLICATIONS
  WIND TUNNELS
  MATERIAL PROCESSING

- TWO APPROACHES
  SiC DIAPHRAM ON Si
  SiC DIAPHRAM ON SiC



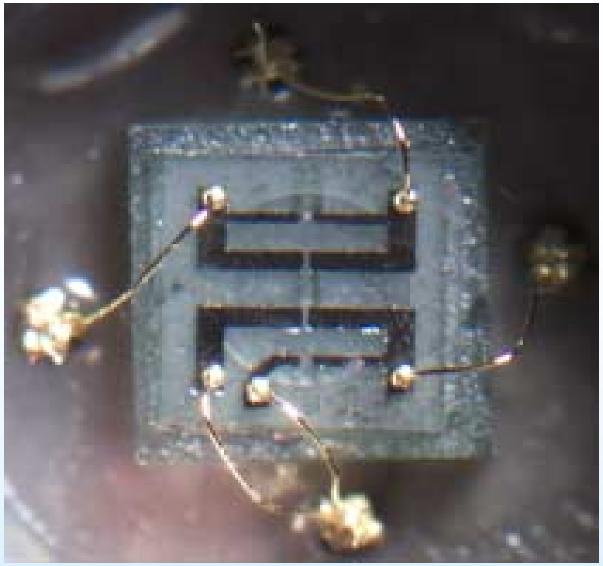
SiC Pressure Sensor
with Electronics

HIGH TEMPERATURE SIC PRESSURE SENSORS:

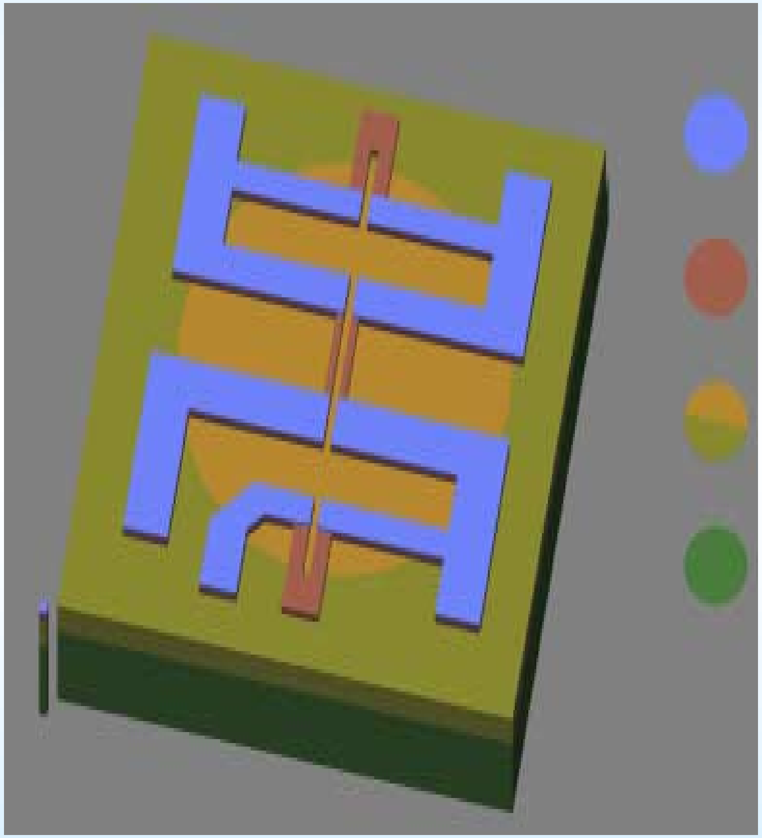
KEY TECHNOLOGIES

Key technologies:

- **SiC micromachining**
- **High temperature contacts**
- **High temperature packaging**



SiC pressure sensor, magnified



metal contacts
Ti / $TaSi_2$ / Pt

strain gages
n-type SiC

isolation layer
p-type SiC

substrate
n-type SiC

Diagram of SiC pressure sensor

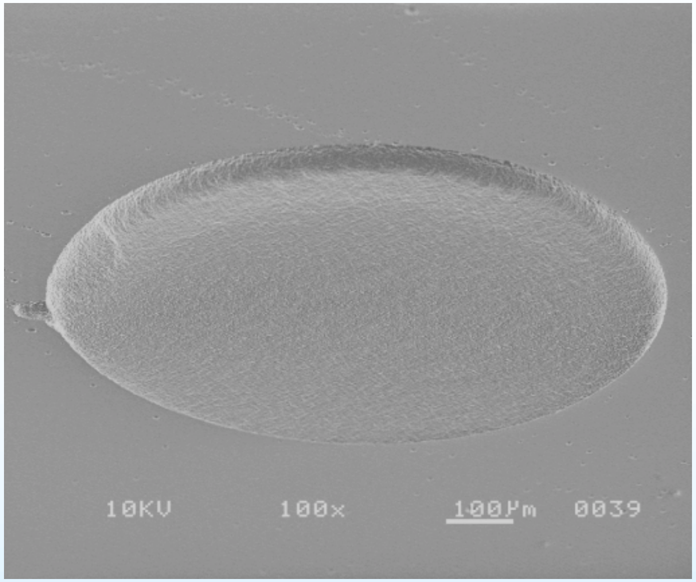
TECHNOLOGY DEVELOPMENT: SIC MICROMACHINING

SiC is chemically inert and therefore difficult to micromachine

Micromachining methods for SiC:

• Electrochemical etching

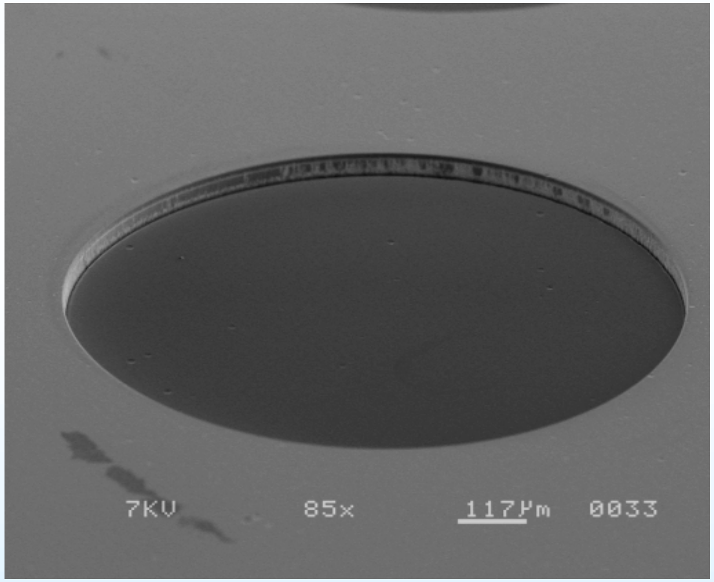
- developed by Kulite, early 1990's



Backside of SiC diaphragm fabricated by electrochemical etching
60 µm etch depth; 1 mm diam

• Deep reactive ion etching (DRIE)

- developed by GRC, 1999



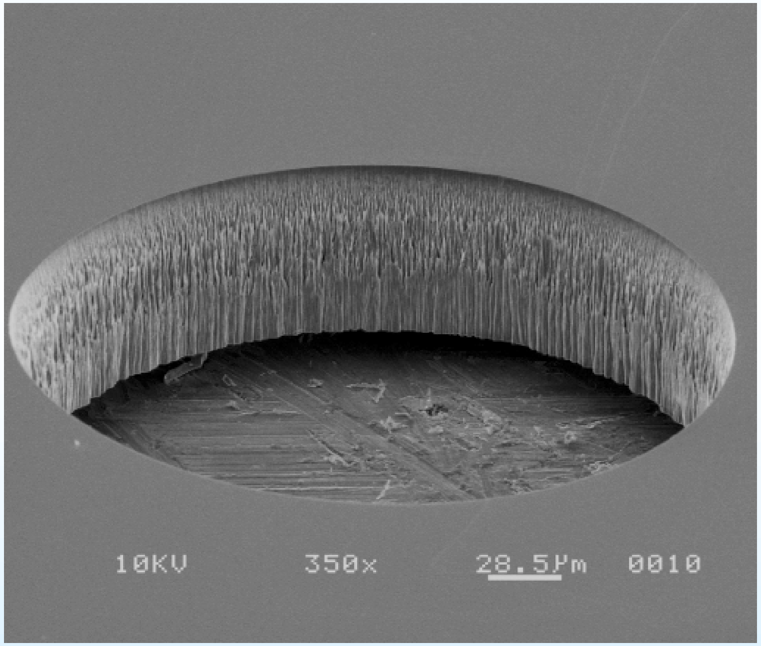
Backside of SiC diaphragm fabricated by DRIE
50 µm etch depth; 1 mm diam

TECHNOLOGY DEVELOPMENT: SIC MICROMACHINING

Advantages of DRIE micromachining process for SiC:

- **Provides vertical sidewalls, smooth etched surfaces**
- **Uses a durable and readily applied etch mask (nickel or indium-tin-oxide)**
- **High rate (0.3 μm/min); uses automated equipment**

DRIE system in GRC cleanroom

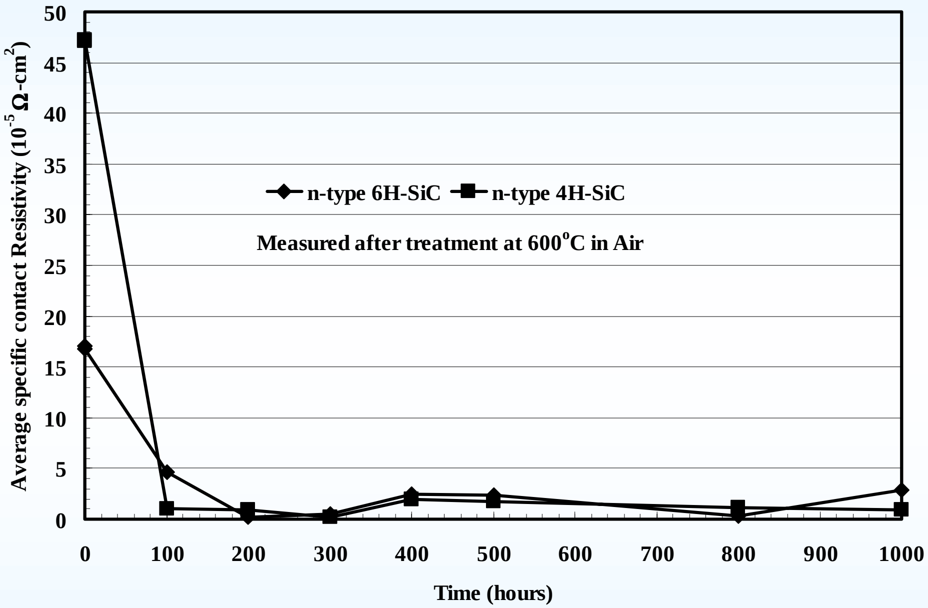


Hole etched by DRIE through a 100 μm thick SiC wafer

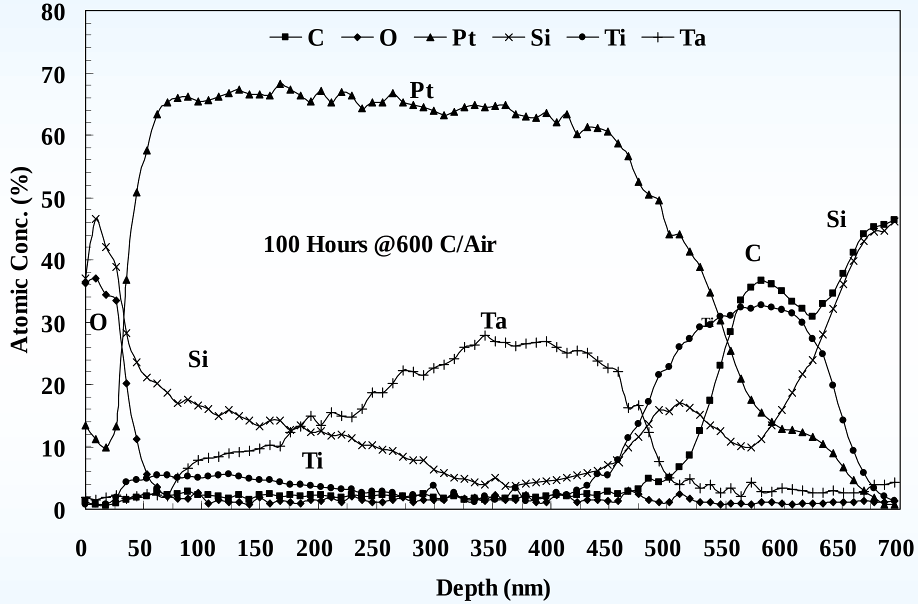
The DRIE process for SiC is an enabling technology for harsh environment MEMS

TECHNOLOGY DEVELOPMENT: HIGH TEMPERATURE CONTACTS

A three layer contact structure, titanium/tantalum silicide/platinum, has shown minimal degradation in performance after more than 1000 hrs at 600 °C

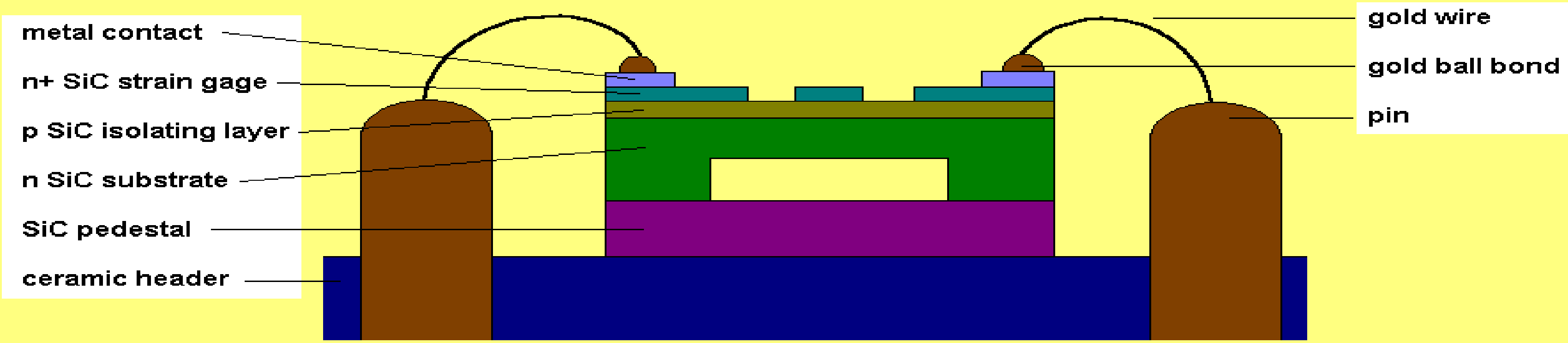


Contact resistance as a function of time exposed to 600 °C. Recently, 1000 hrs at 600 °C has been demonstrated.



Auger depth profile of contact exposed to 600 °C for 100 hrs. Following burn-in, a platinum silicide diffusion barrier is formed, which protects the underlying layers from oxidation.

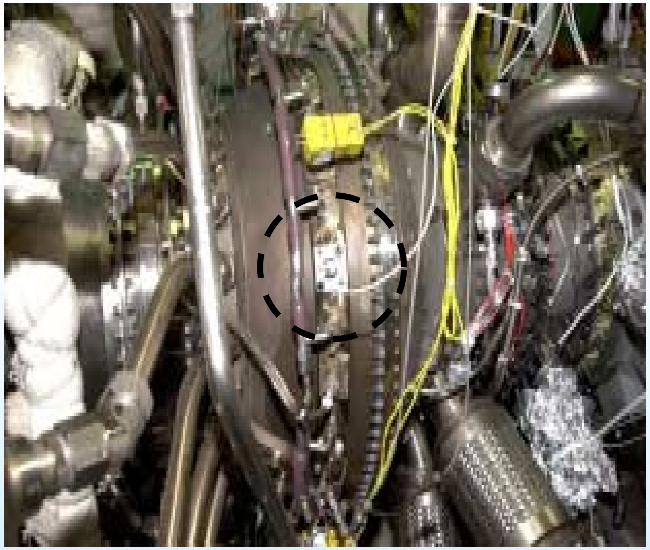
TECHNOLOGY DEVELOPMENT:
HIGH TEMPERATURE SiC PRESSURE SENSOR PACKAGING

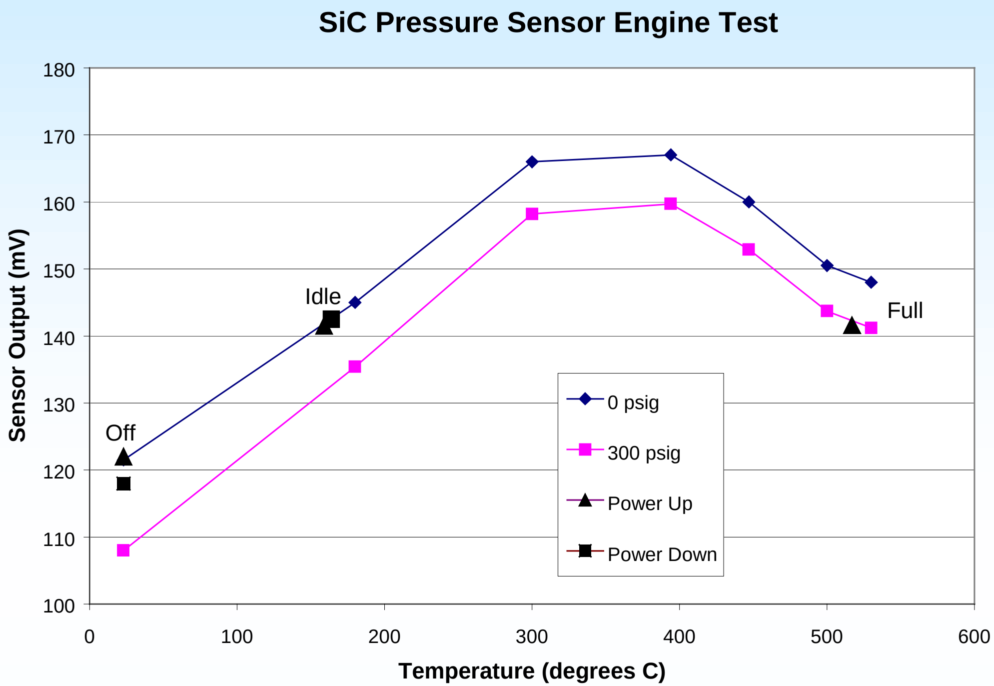


Cross section of SiC pressure sensor package

High Temperature SiC Pressure Sensor: Engine Test

Above: 500 °C SiC pressure sensor



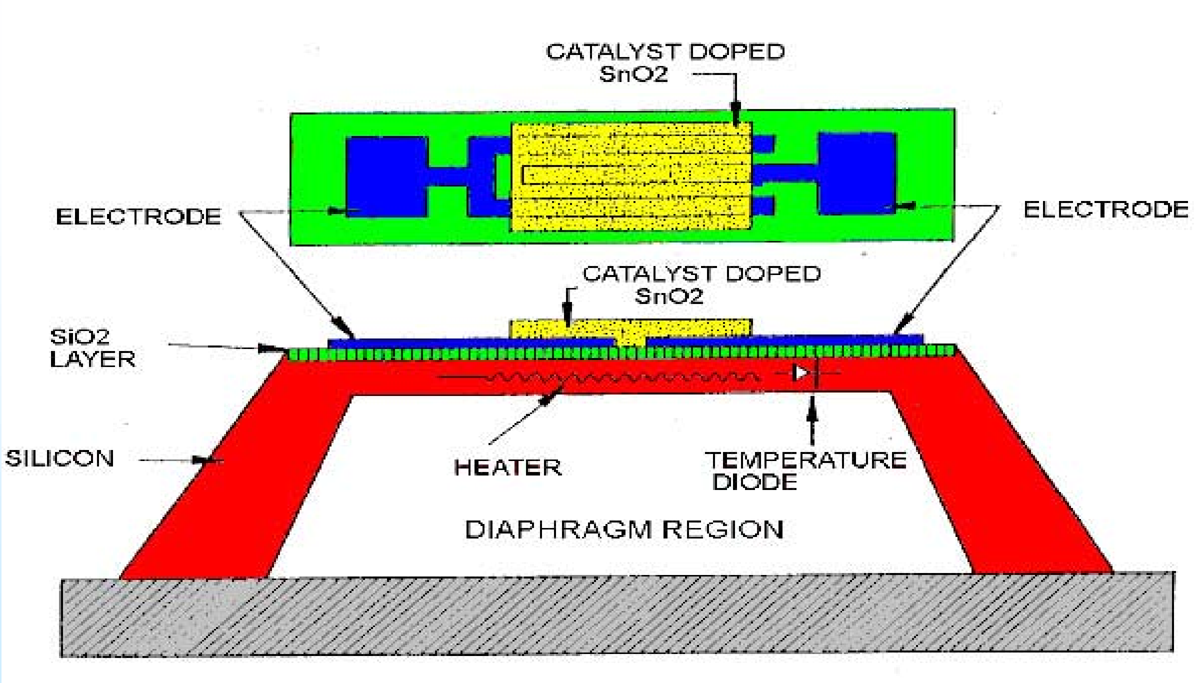


Above: data from the engine test is superimposed on calibration data for the sensor. A 4 mV output shift is produced upon exposure to the peak temperature. Further work will aim to decrease sensor drift.

Left: SiC pressure sensor installed in compressor deswirl region of Honeywell AS907 core engine.

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

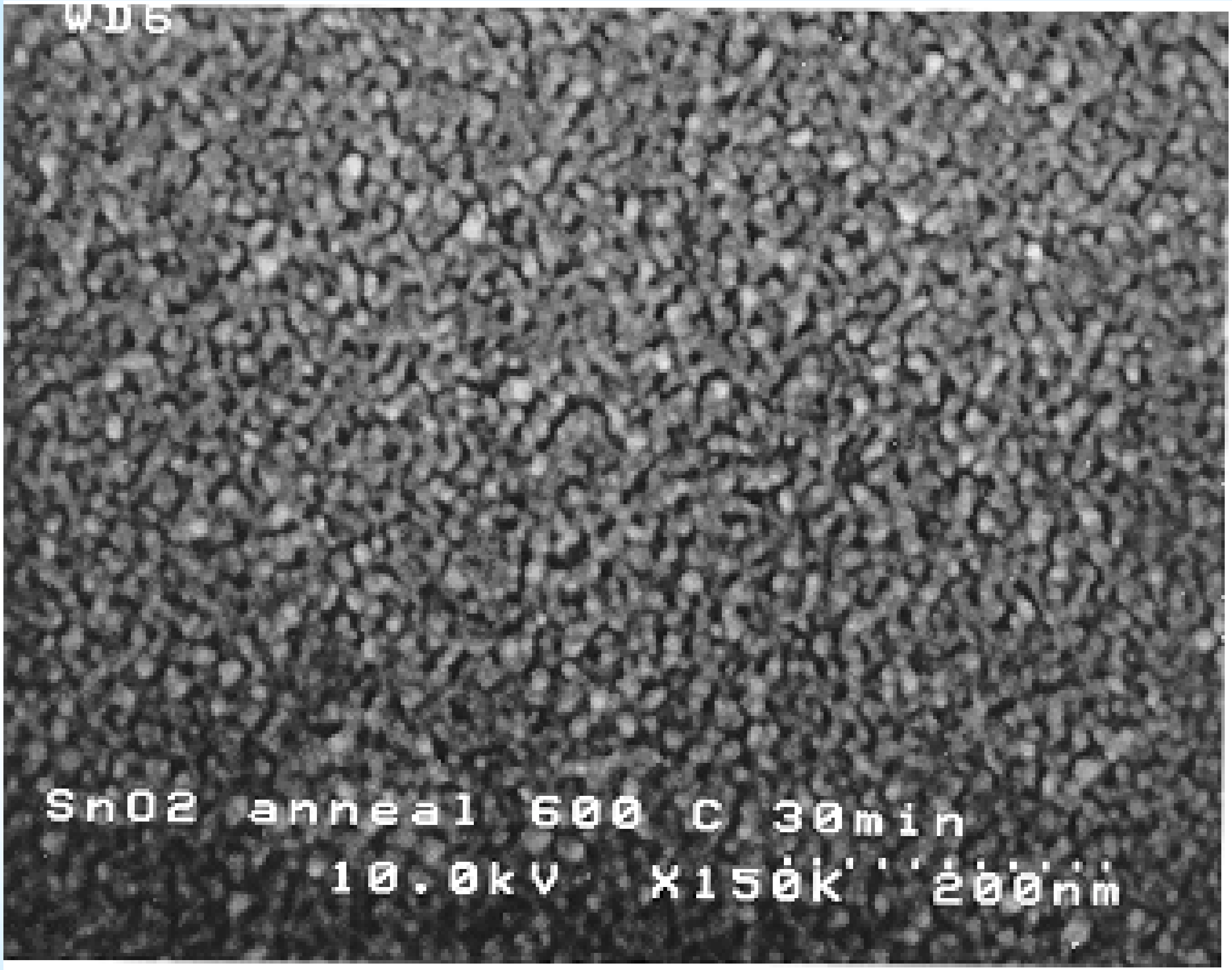
ALTERNATE PROCESSING YIELDS IMPROVED SENSOR PROPERTIES

PROPERTIES OF NANOCRYSTALLINE SNO2 THIN FILM FROM SOL-GEL PROCESS

- SMALL PARTICLE SIZE
- HIGH POROSITY
- LARGE SURFACE AREA
- HOMOGENEOUS CHEMICAL AND PHYSICAL STRUCTURE

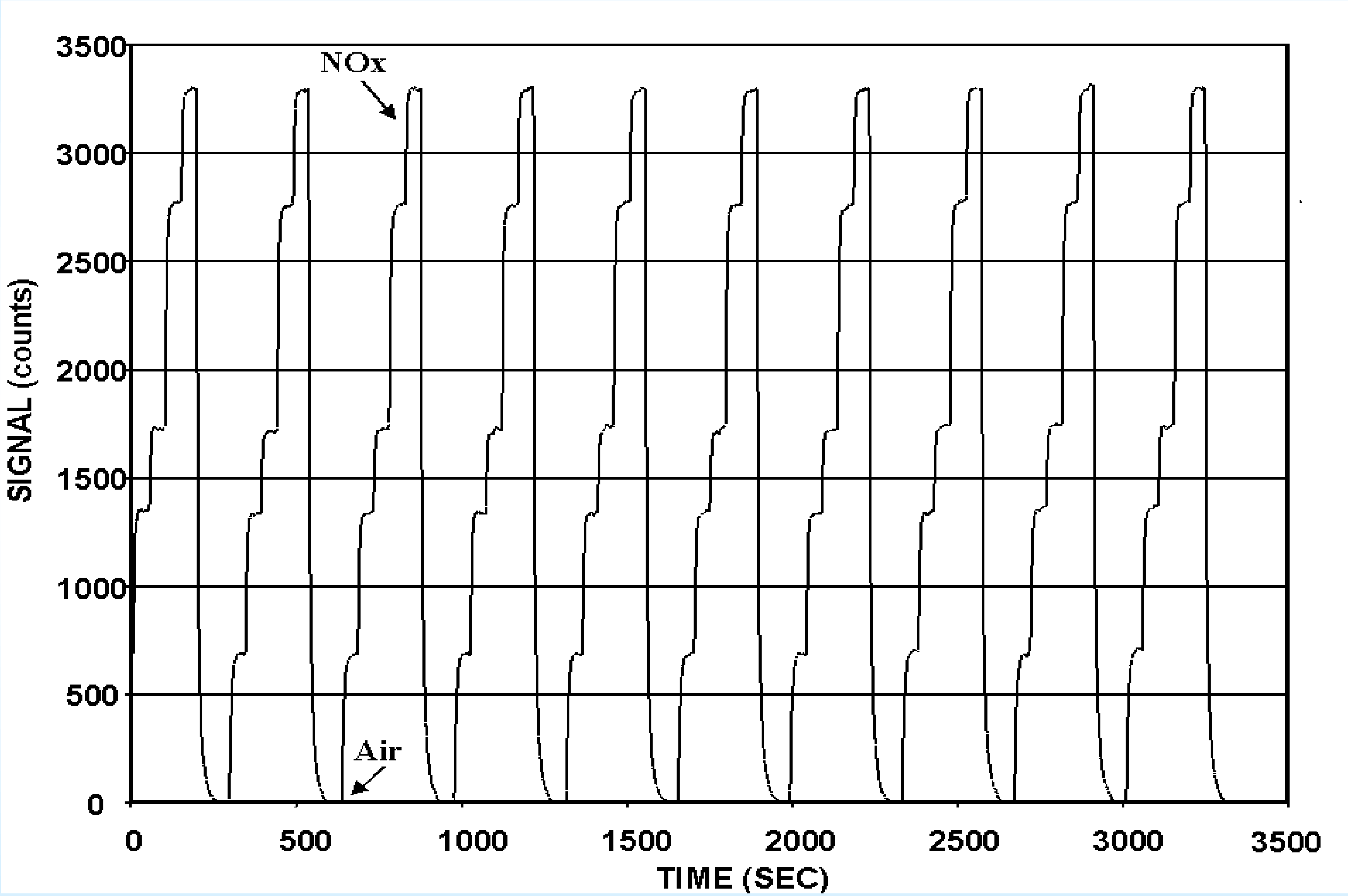
ADVANTAGES FOR SENSOR APPLICATIONS

- HIGH SENSITIVITY
- FAST RESPONSE
- STABLE OPERATION



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

THE RESPONSE OF A DOPED SNO_2 SENSOR TO CYCLED CONCENTRATIONS OF NO_X



STEPS: 0 TO 3 TO 6 TO 12 TO 25 TO 50 PPM AND BACK TO 0 IN AIR

T= 350°C

PACKAGING TAILORED FOR THE APPLICATION

SnO_2 SENSORS ON CERAMIC SUBSTRATE RATHER THAN SILICON FOR ENGINE TESTING

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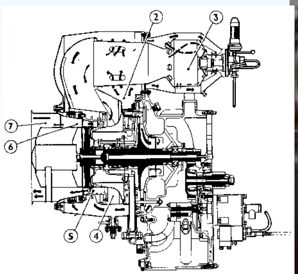
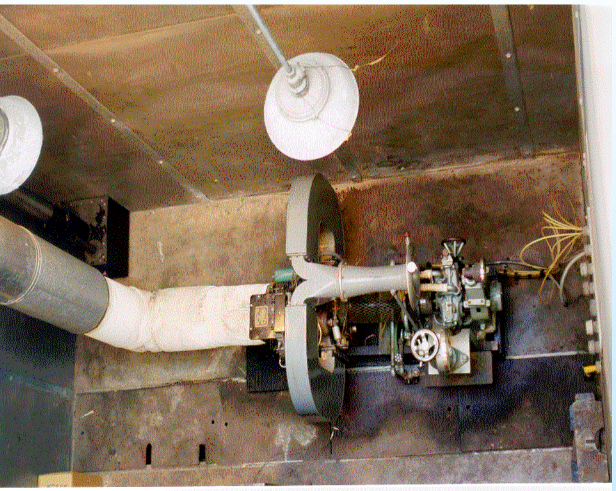
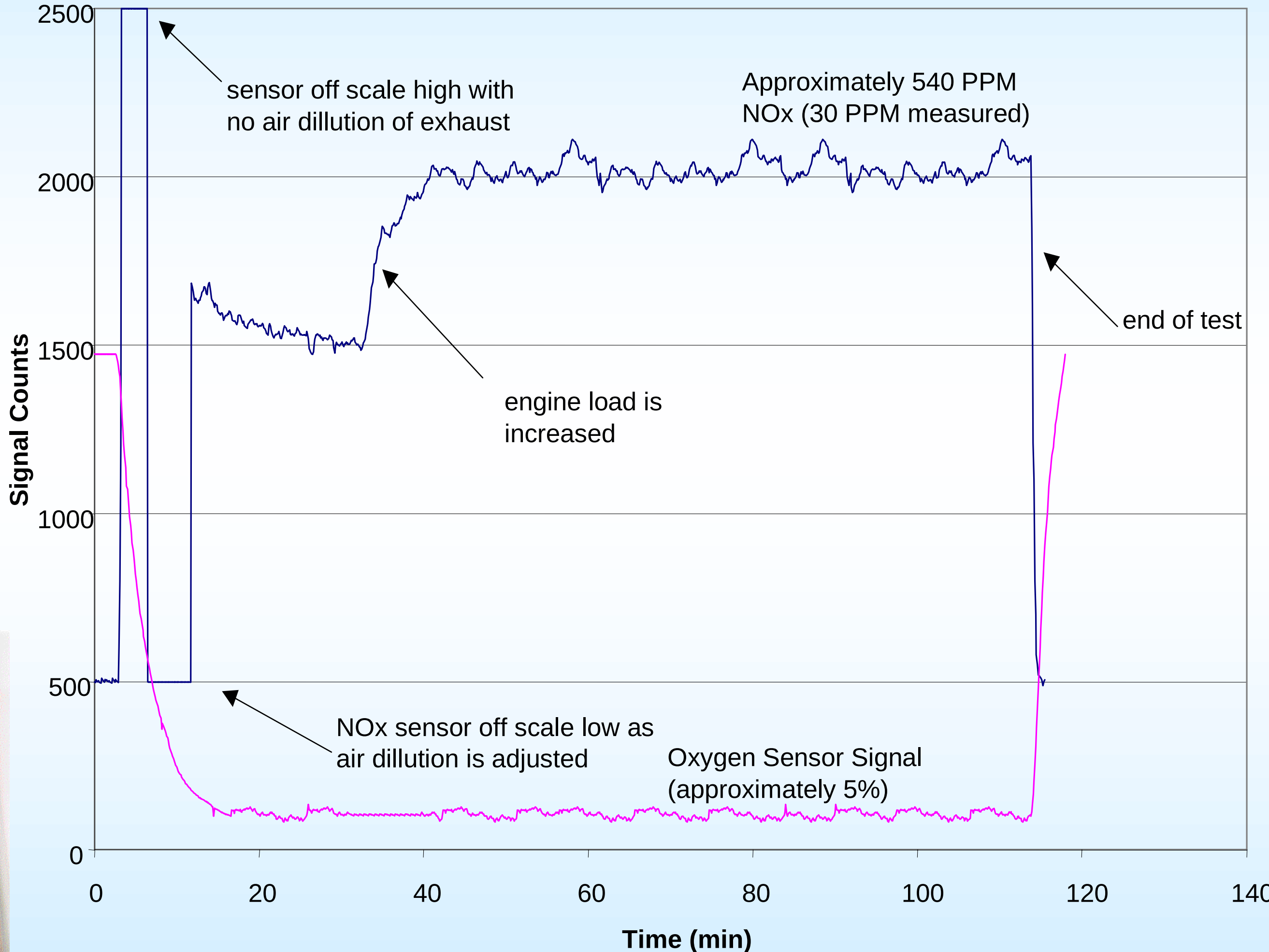
Demonstration Testing Of NOx Sensor In Gas Turbine Exhaust Stream



50 Hp Gas Turbine

Industry Standard Continuous Emission Monitoring Equipment





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

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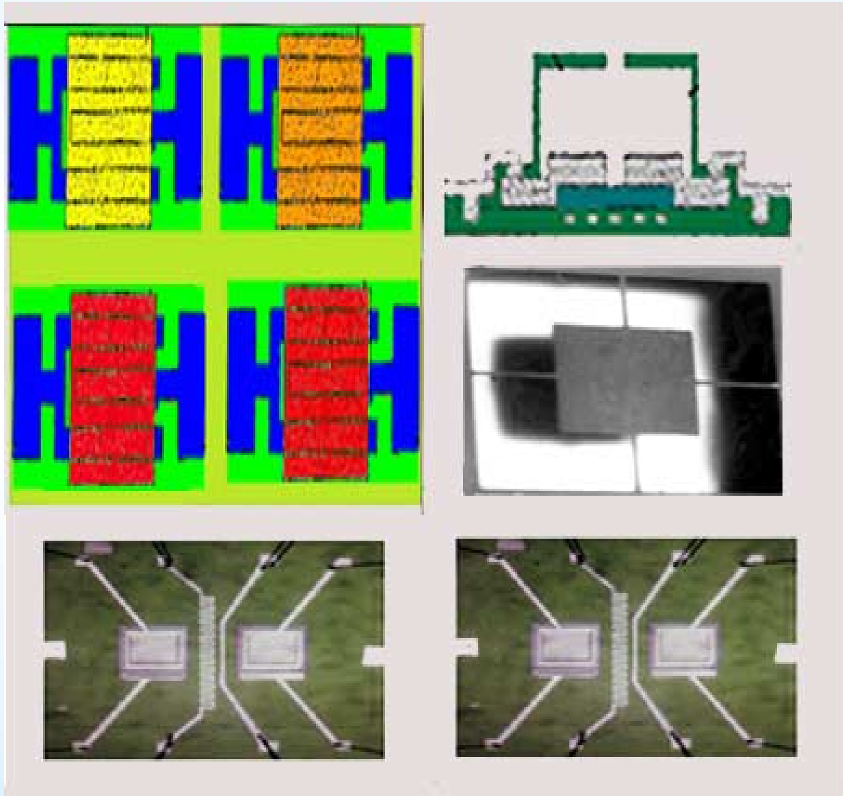
GLENNAN MICROSYSTEM INITIATIVE

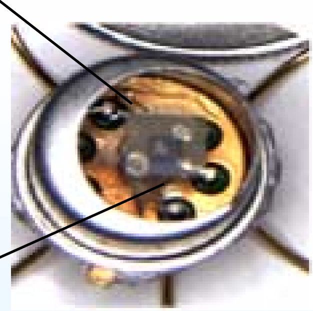
MICROFABRICATED EMISSION SENSOR ARRAY CONCEPT
HIGH TEMPERATURE ELECTRONIC NOSE

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**

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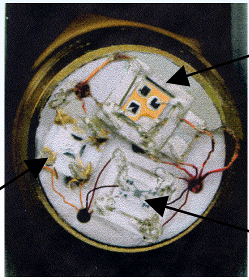
Brassboard Integrated Electronic Nose System

High Temperature Nose Requires Packaging Beyond Room Temperature Systems



•SiC Hydrocarbon Sensors From NASA GRC

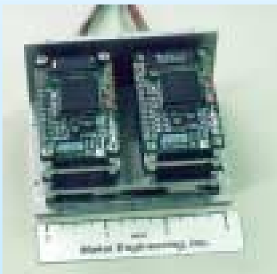
•OSU Sensor

•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)

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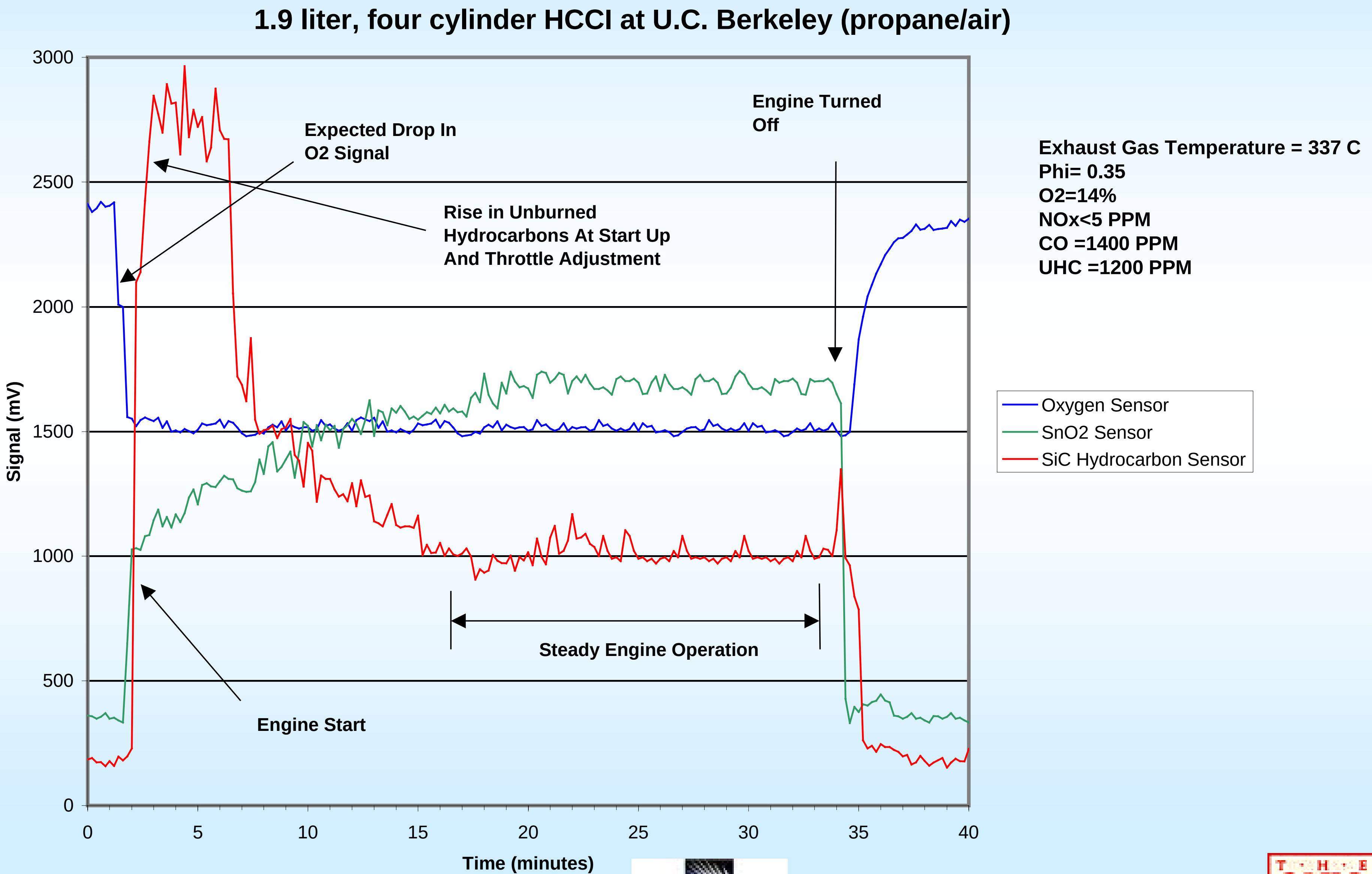
GLENNAN

Harsh Environment Demonstration Testing



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SUMMARY

- RELIABILITY IS A SIGNIFICANT ISSUE IN HIGH TEMPERATURE SENSORS AND ELECTRONICS

  PHYSICAL AND CHEMICAL SENSORS
  HIGH TEMPERATURE ELECTRONICS/SENSORS

- SENSOR AND ELECTRONICS DEVELOPMENT

  TAILOR DEVICE TO APPLICATION/WHOLE SYSTEM APPROACH
  MULTILAYER LAYER APPROACHES NECESSARY
  NEW MATERIALS DEVELOPMENT

- CONNECTIONS WITH FROM DEVICE TO OUTSIDE USER A MAJOR COMPONENT OF DEVICE RELIABILITY

  LEAD WIRES
  CONTACTS
  PACKAGING

- DEMANDS ON RELIABLITY OF INDIVIDUAL COMPONENTS WILL INCREASE WITH THE DEVELOPMENT OF INTEGRATED MICROSYSTEMS