KSC Efforts at Miniaturization and Ruggedization of Mass Spectrometers

& Other Topics Not Mentioned Earlier

F. W. Adams / NASA / KSC

Duke Follistein / NASA / KSC

KSC Requirements

- Mass Analyzers (systems)
  - H2, He, N2, O2, Ar, CO2
  - Background gas: Helium, Nitrogen or Air
  - Sensitivity to ppm's at low concentration
  - Wide dynamic range (10K - 100K)
  - Small, Rugged, Reliable
- Backing and High-Vacuum Pumps
- Sample Delivery Systems and Components
- Point Sensors and Multiplexors

Mass Analyzers

- Ionization
  - Solid State free-electron source (SBIR)
  - Efficiency enhancement concept (TBD)
  - Monolithic Block construction
- Mass Filter
  - Simplified Time-of-Flight (SBIR)
  - Ortho Time of Flight (SBIR)
  - Ion-Trap (Grant, U/F)
- Detectors
  - Miniaturized electron multipliers
  - Ruggedized micro-channel plate assemblies
  - Monolithic block construction

Pumps (Backing, High-Vacuum)

- Miniaturization
  - JPL Miniature Pumps Effort
  - Rotary Backing Pumps (Summer Faculty)
- Ruggedization
  - Creare SBIR Turbo-molecular pump
  - Solid-State Free-electron Source
  - Ionization-Efficiency enhancement
  - Ion Engine Concept

Sample Delivery / Components

- Manifolds and Fittings
  - Fabrication and Reliability
- Miniature pressure regulators
  - Rugged, Reference against vacuum
- Miniature Valves
  - Reliable, Leak Tight, Low dead volume
- Miniature Flow Controllers
  - Rugged, Reliable, Low dead volume

Point Sensors (Reduced Sensitivity)

- Cryo Operation
  - Point Hydrogen, Oxygen sensors
  - Reduce response time
- Ground Support Equipment
  - Cryo operation
  - Room temperature
- Flight Vehicles
  - On-board, IVHM

Funding Mechanisms (Historical)

- Small Business Innovation Research
  - Creare / Rugged, Miniature High-Vacuum Pump
  - IonWerks / Solid-State Free Electron Source
  - Intelligent Optical Sensors / Fiber O2, H2 Sensors
  - Southwest Sciences, Inc / Unique TOF Approach
  - Makel Engineering, Inc. / Point Sensors H2 / O2
- Internal Funding
  - Engineering Technology Base (ETB)
  - Space Launch Initiative / Second Generation RLV
- Partnerships
  - Local Universities
  - Summer Faculty Fellowships

Funding / Internal

- Engineering Technology Base (ETB)
- Space Launch Initiative / 2nd Gen RLV
- 3rd Gen Recently Cancelled
- Center Director's Discretionary Fund (CDDF)
- Shuttle Projects
- Air Force, Navy, Army, etc.

Funding, Partnerships

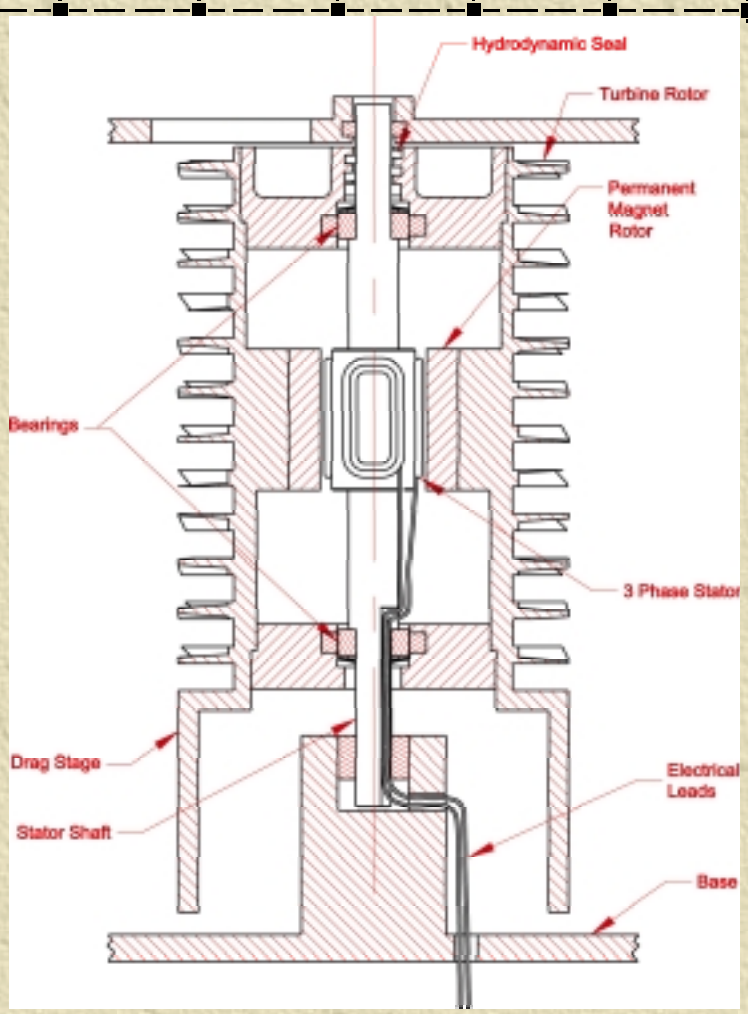
- Local Universities
  - Florida Solar Energy Center (MEMS Fab)
  - Florida Institute of Technology (Fiber optics)
  - University of Florida (Ion-Trap)
- Summer Faculty Fellowships
  - Concept Generation and evaluation
  - Experimental research
  - Detail design and performance evaluation

SBIR / Phase-I / CREARE

Creare

- Under a KSC-sponsored SBIR, Creare Inc. is building a highly ruggedized version of a recently developed 5 L/s turbomolecular pump
- Miniaturized and rugged high vacuum systems are needed to complement recently developed portable mass spectrometers
- A key innovation of the new version is an “inside-out” electric motor that replaces the typical cantilevered rotor with one supported at both top and bottom, providing high tolerance to vibration and shock
- The TMP will be combined with a modified version of a commercial rough pump to form a complete vacuum system

SBIR / Phase-I / Creare

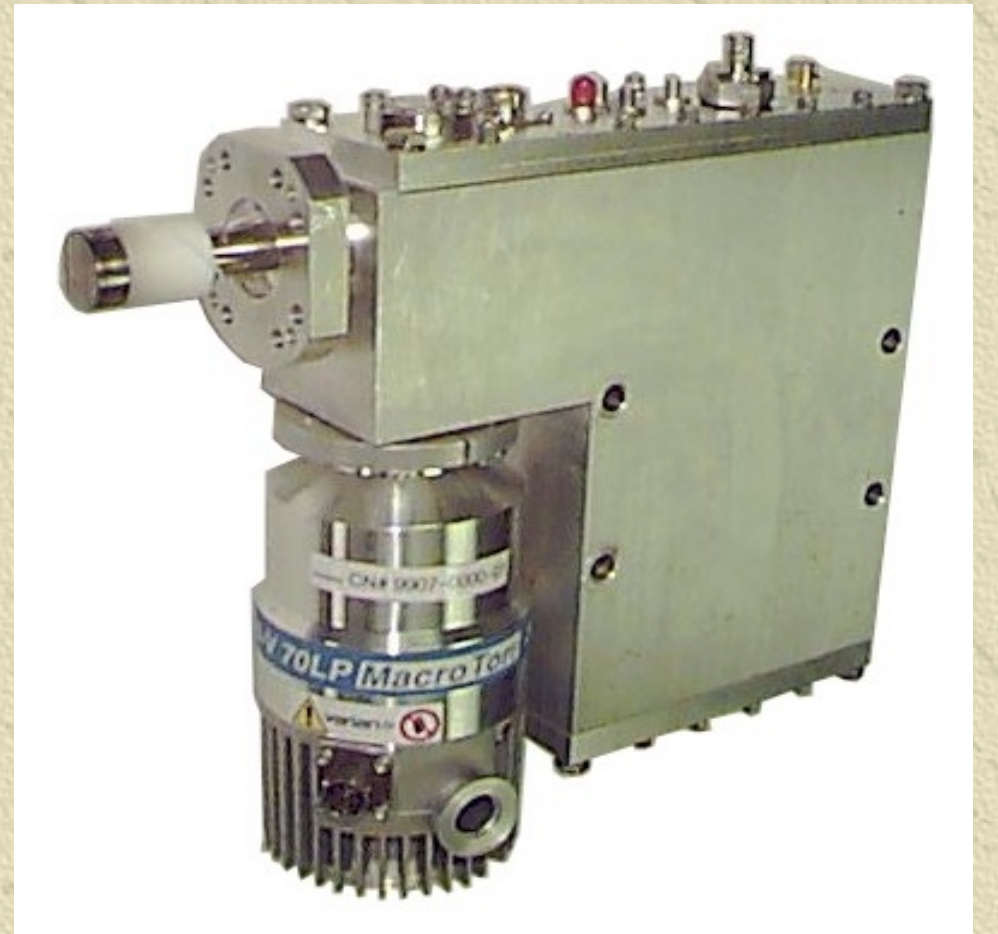


SBIR / Phase-II / IonWerks

- IonWerks
- Al Schultz, Katrin Fuhrer, Marc Gonin
  - Solid-State Free Electron Source
    - Rugged
    - Reliable
  - Applications
    - Analyzer ionizer
    - Ion-engine based high vacuum pump

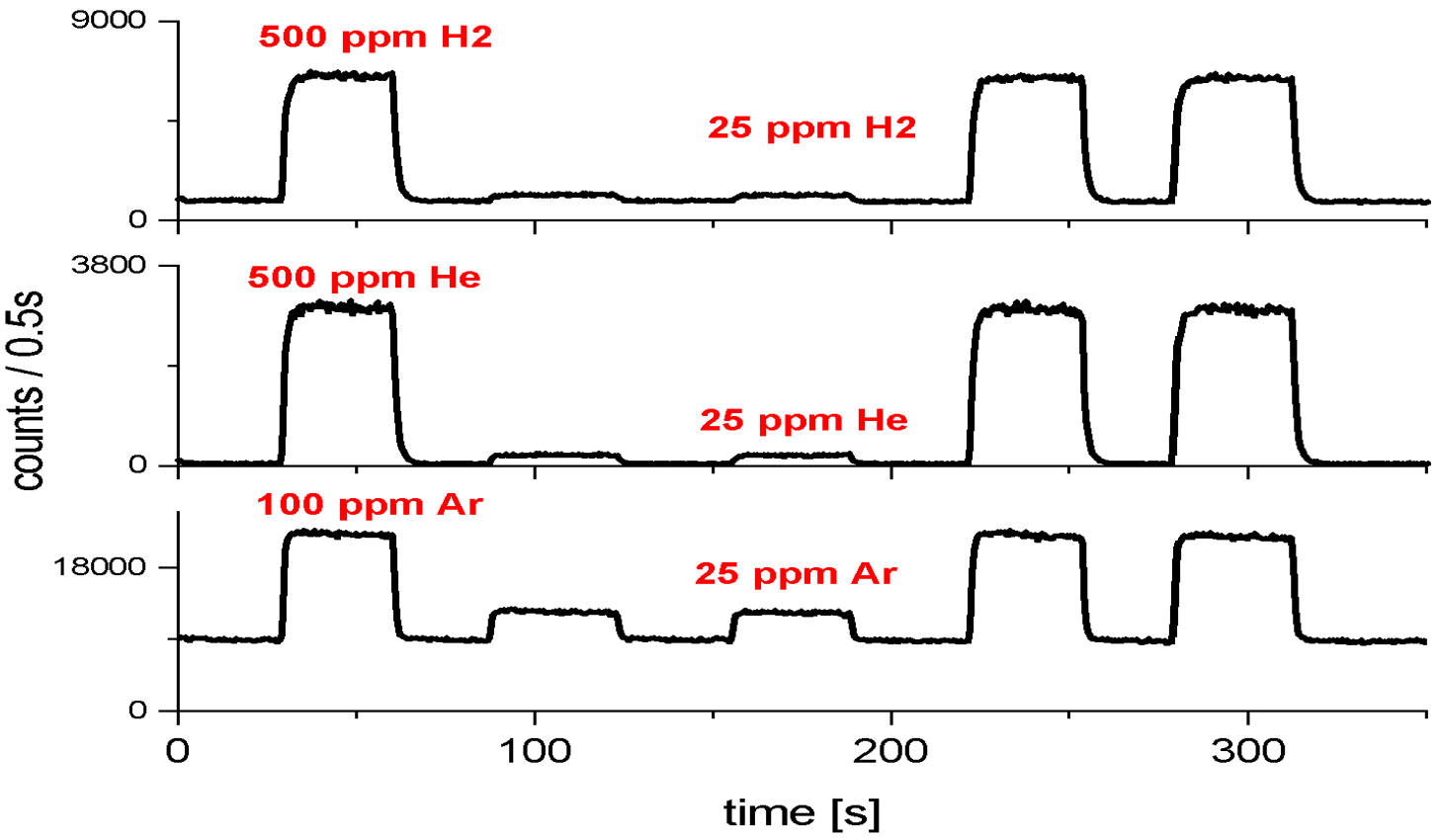
SBIR / Phase-II / IonWerks

Goals
-rugged
-compact
-high sampling speed

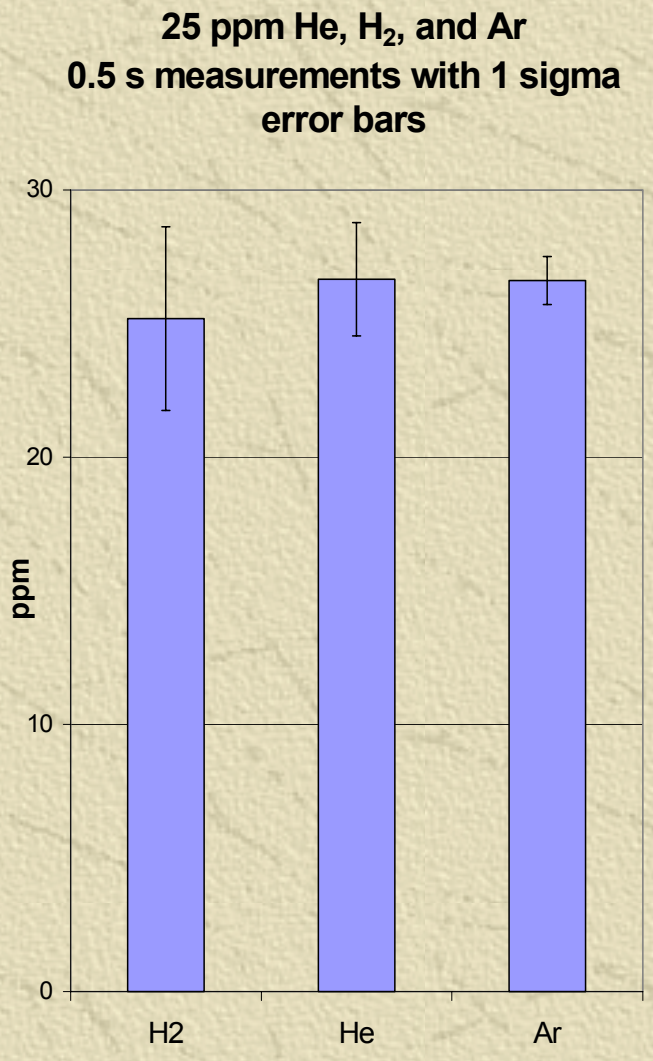


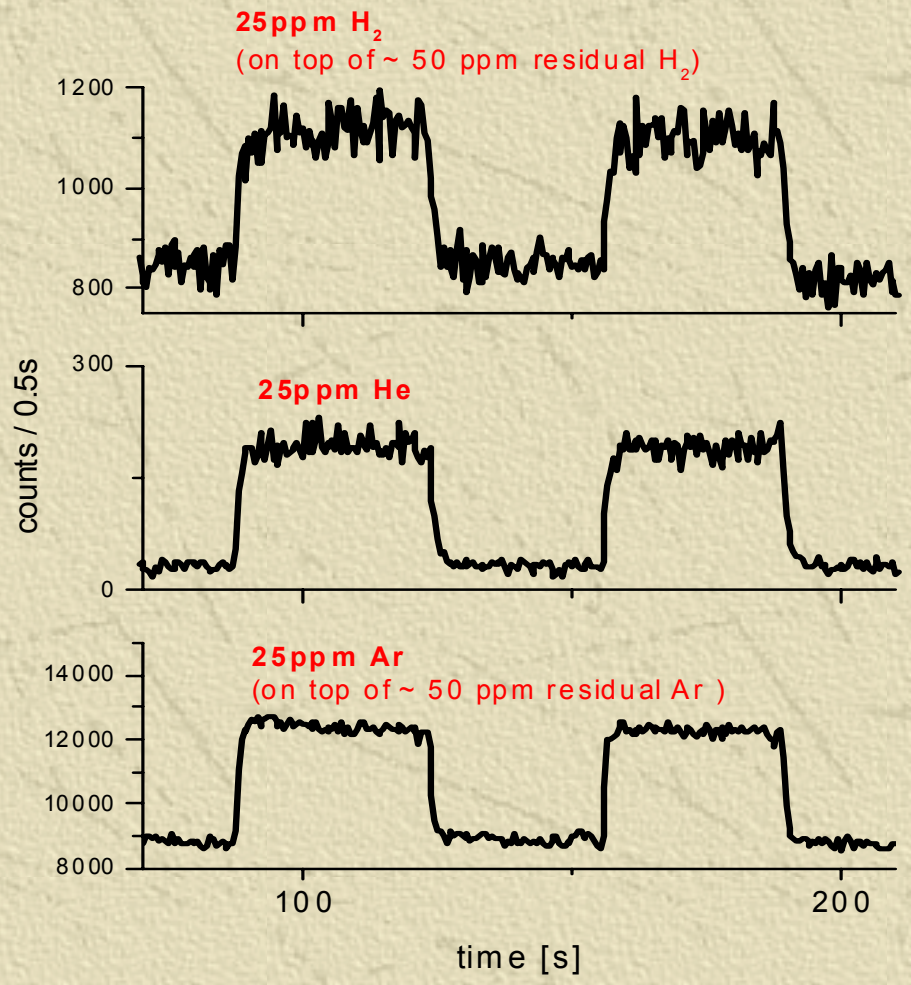
SBIR / Phase-II / IonWerks

H_2, He and Ar test gases in Nitrogen

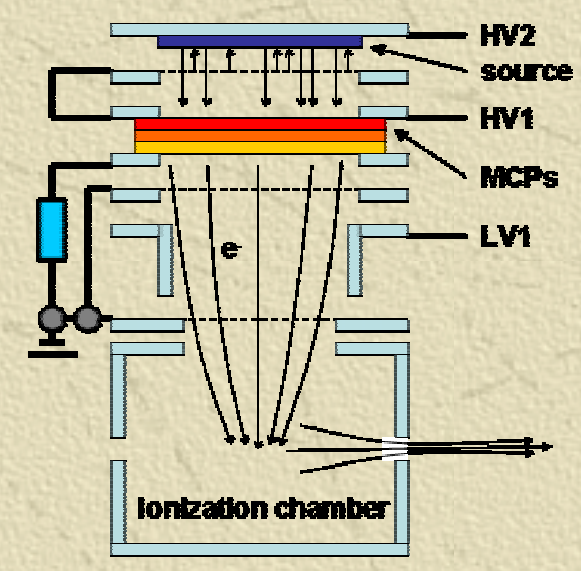


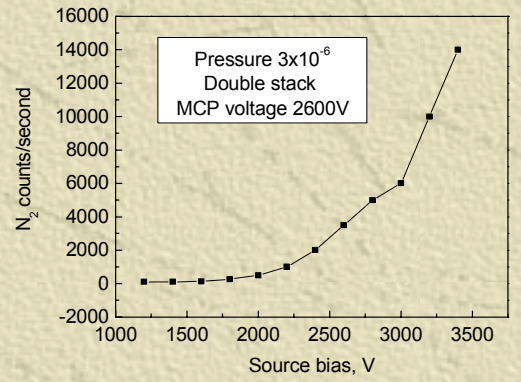
SBIR / Phase-II / IonWerks





SBIR / Phase-II / IonWerks





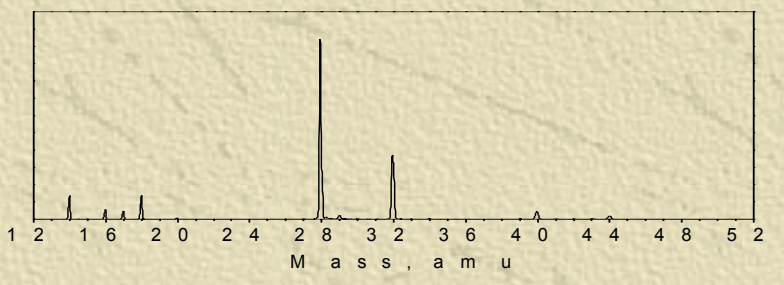
Performance update

Source-grid design with double/triple stack MCP electron current multiplier

1. Operation efficiency: comparable to that of the filament ionizer with 100nA electron emission current.
2. Emission current stability about 3%.

Further improvements

1. High gain/high maximum output (up to 100 μA) single channel electron current multiplier will be used.
2. High tension grid will be utilized in order to improve the emission stability.
3. Extra multiplication stage will be added if necessary.



SBIR / Phase-II / IonWerks

O-TOF: Current status

- 50’000 mass spectra per second
- 0.1 s response time with capillary interface
- Spectra currently averaged over 0.5 s:
  25 ppm H2, He measured with 10% error in 0.5 s
  25 ppm Ar measured with 5% error in 0.5 s
- Filamentless ionizer under development for increased ruggedness

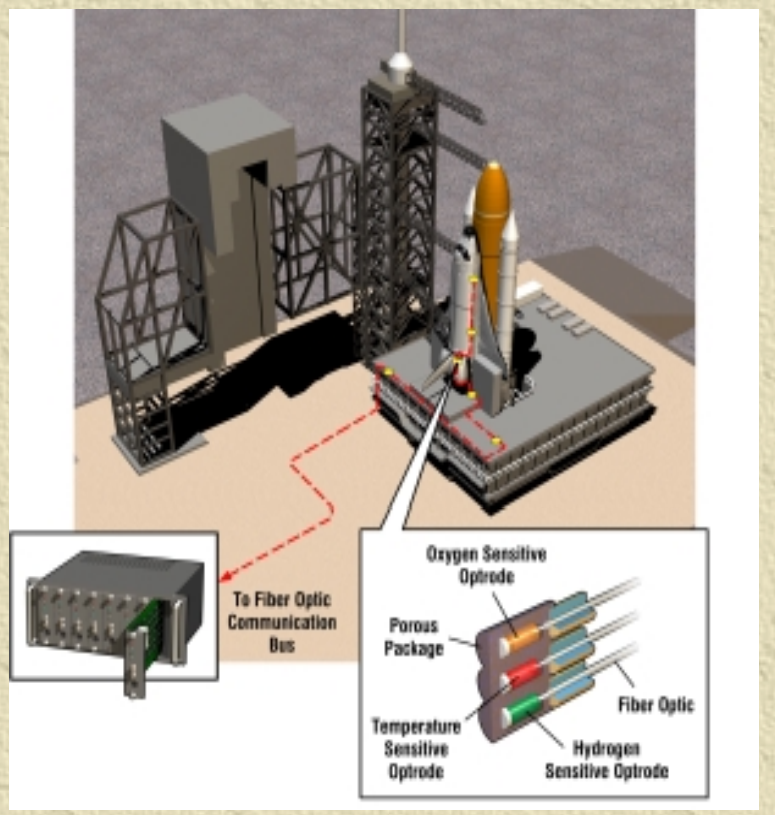
Future development:

- Increase sampling speed
- Shrink electronics
- Implement filamentless ionizer

SBIR / Phase-I / IOS

- Kisholoy Goswami (PI)
- Intelligent Optical Sensors
  - Fiber H2, O2 Sensors
  - Multiplex features
  - Functions demonstrated

SBIR / Phase-I / IOS



- Intelligent Optical Systems (IOS) is now developing gas sensors for use on and around space launch vehicles

SBIR / Phase-I / IOS

- Project Goals (Long-term, Phase III)
  - Demonstrate that H2 and O2 can be detected in real-time (within a second) in the ppm – 100% range.
  - Establish that at least 20 sensors can be multiplexed at a cost of $10,000 or under.
  - The sensors monitor these gases continuously.

SBIR / Phase-I / IOS

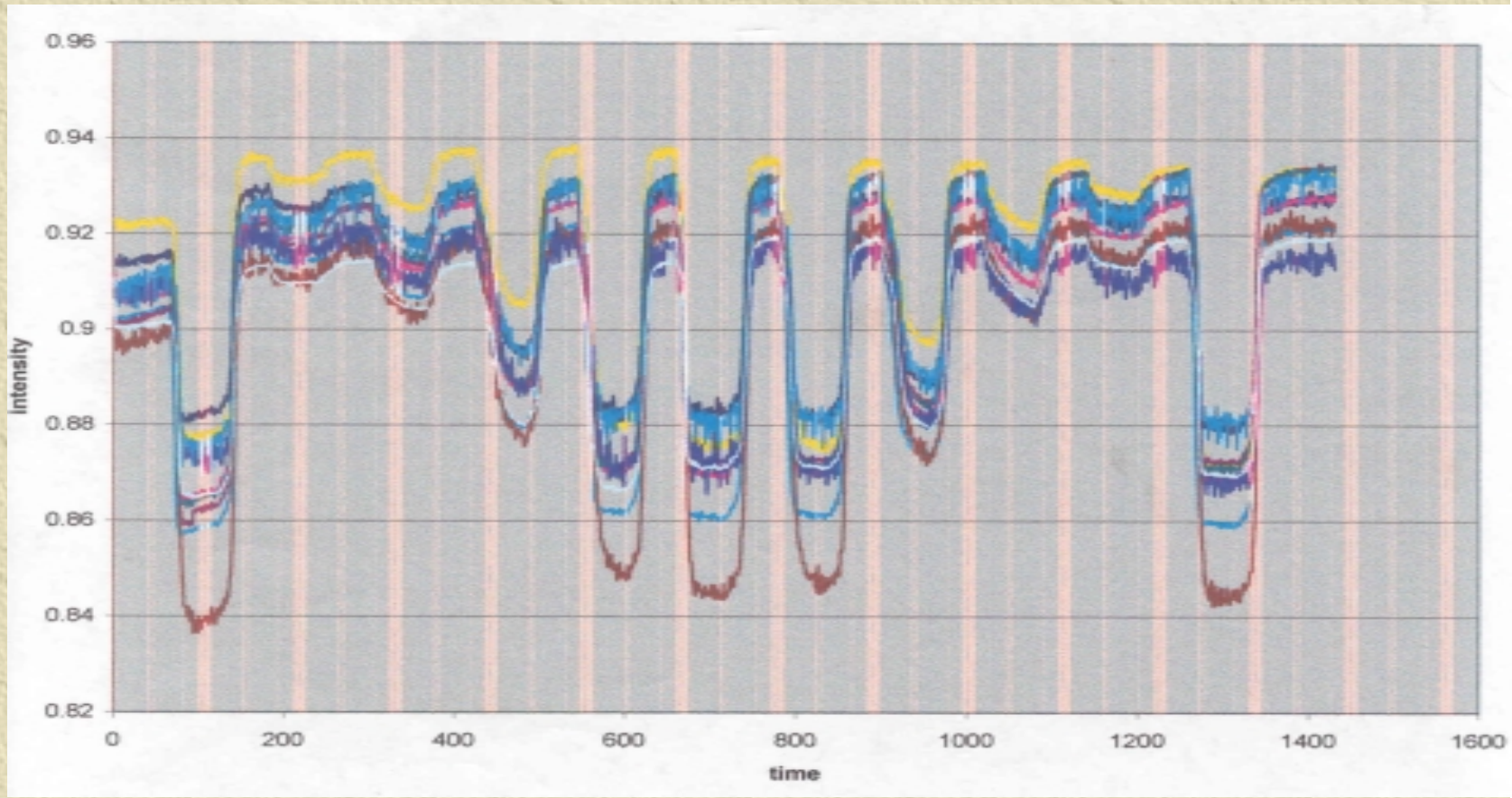
Mixed, Phase I, II, III

PARAMETER	O_2 SENSOR	H_2 SENSOR
RANGE	0.1% TO 10%	0.1% TO 10%
RESPONSE TIME	~ 1 Second	~ 1 Second
ACCURACY	± 1% of Reading	± 1% of Reading
SENSITIVITY	0.10%	0.01%
RESOLUTION	0.10%	0.01%
SELECTIVITY	1-5% Nitrogen	1-5% Nitrogen
	5% Carbon Dioxide	10% Oxygen
	75%-100% RH	75%-100% RH
TEMPERATURE RANGE	0°F - 140°F	0°F - 140°F
DRIFT	< 0.1% per Day	< 0.1% per Day
HALF LIFE OF SENSOR	> I YEAR	> I YEAR
FALSE ALARMS	0	0

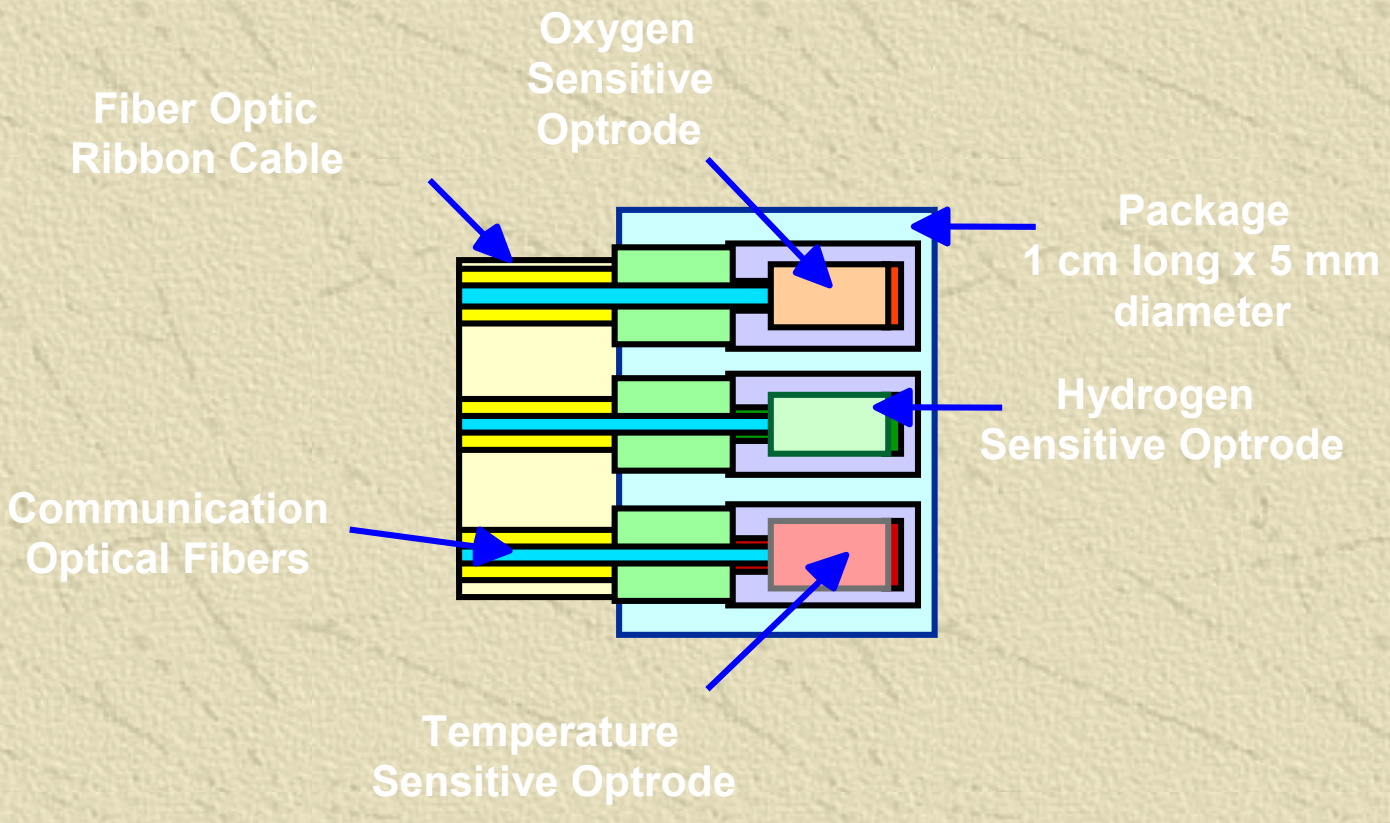
SBIR / Phase-I / IOS

- Demonstrated performance of hydrogen sensors in the range of 0% to 10%
- Demonstrated hydrogen sensor with no cross-sensitivity to nitrogen, helium, or air

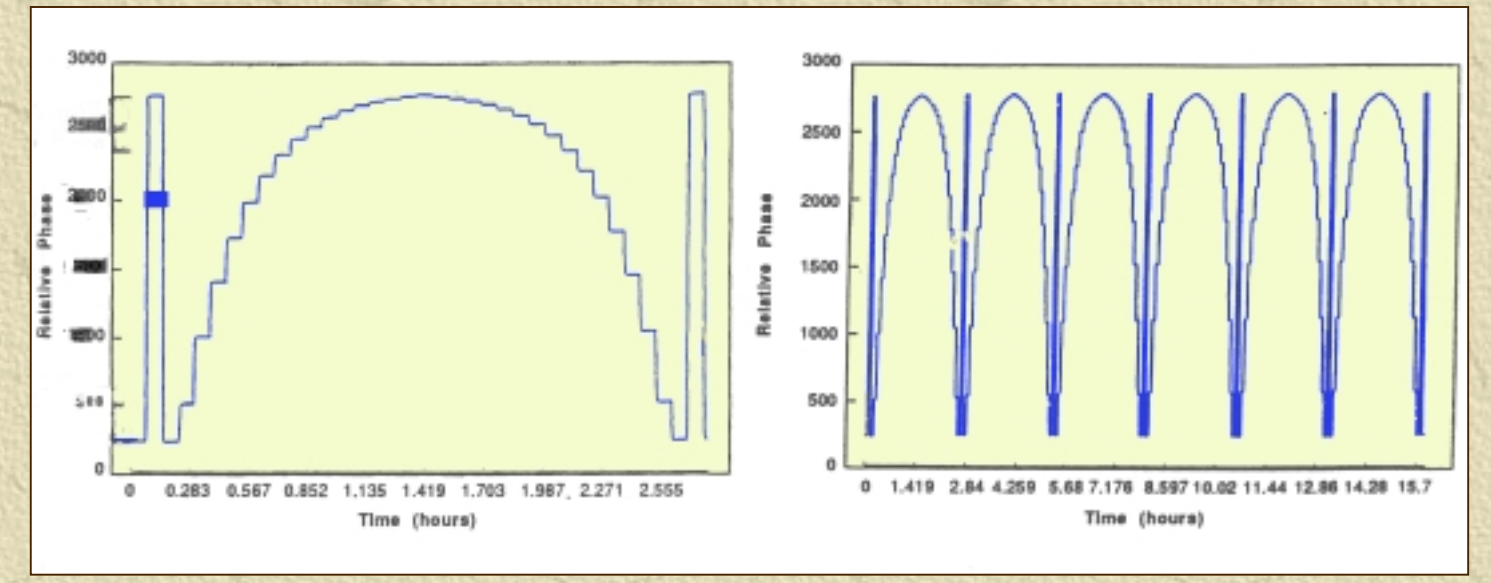
SBIR / Phase-I / IOS



SBIR / Phase-I / IOS



SBIR / Phase-I / IOS



SBIR / Phase-II / Makel

GARY W. HUNTER, Ph.D.
SENSORS AND ELECRONICS BRANCH
INSTRUMENTATION AND CONTROLS DIVISION
NASA GLENN RESEARCH CENTER

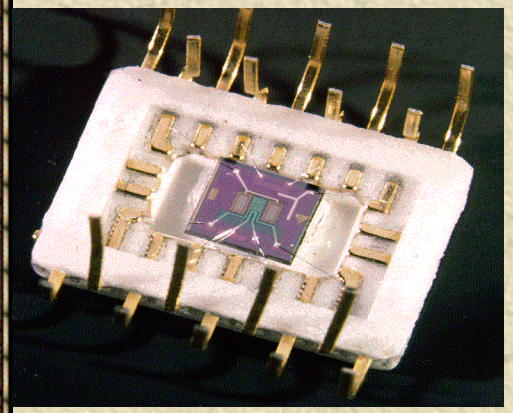
PARTNERS

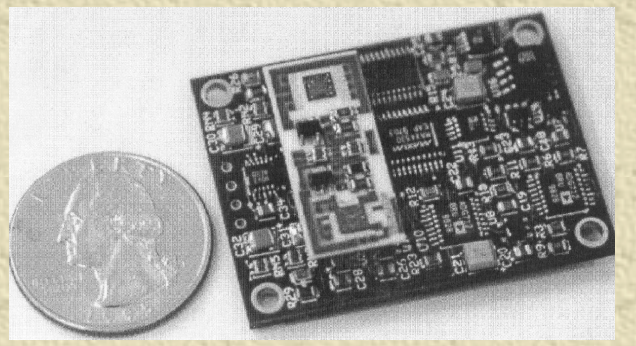
NASA GLENN RESEARCH CENTER
NASA KENNEDY SPACE CENTER
MAKEL ENGINEERING, INC
CASE WESTERN RESERVE UNIVERSITY

SBIR / Phase-II / Makel

- Makel Engineering
  - Chemical H2, O2 Sensors
    - Reliable operation in Helium, Nitrogen or Air
  - Wide dynamic range
    - 100 ppm – 100%
  - Signal Processing
    - On-board sensor assembly

SBIR / Phase-II / Makel





PROTOTYPE HYDROGEN/OXYGEN SENSOR SYSTEM WITH ELECTRONICS

↓

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

SBIR / Phase-II / Makel

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

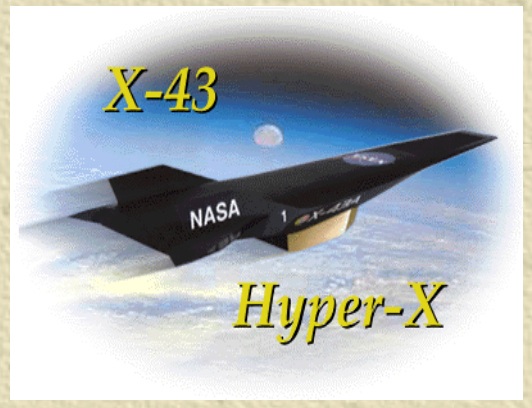
  SCHOTTKY DIODE
  RESISTANCE BASED
  ELECTROCHEMICAL

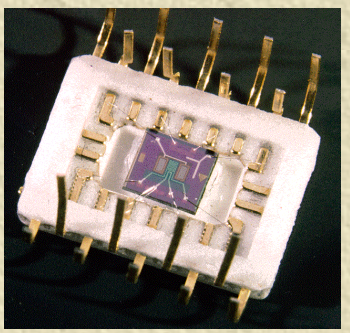
- TARGET DETECTION OF GASES OF FUNDAMENTAL INTEREST

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

SBIR / Phase-II / Makel

1995 R&D 100 AWARD WINNER

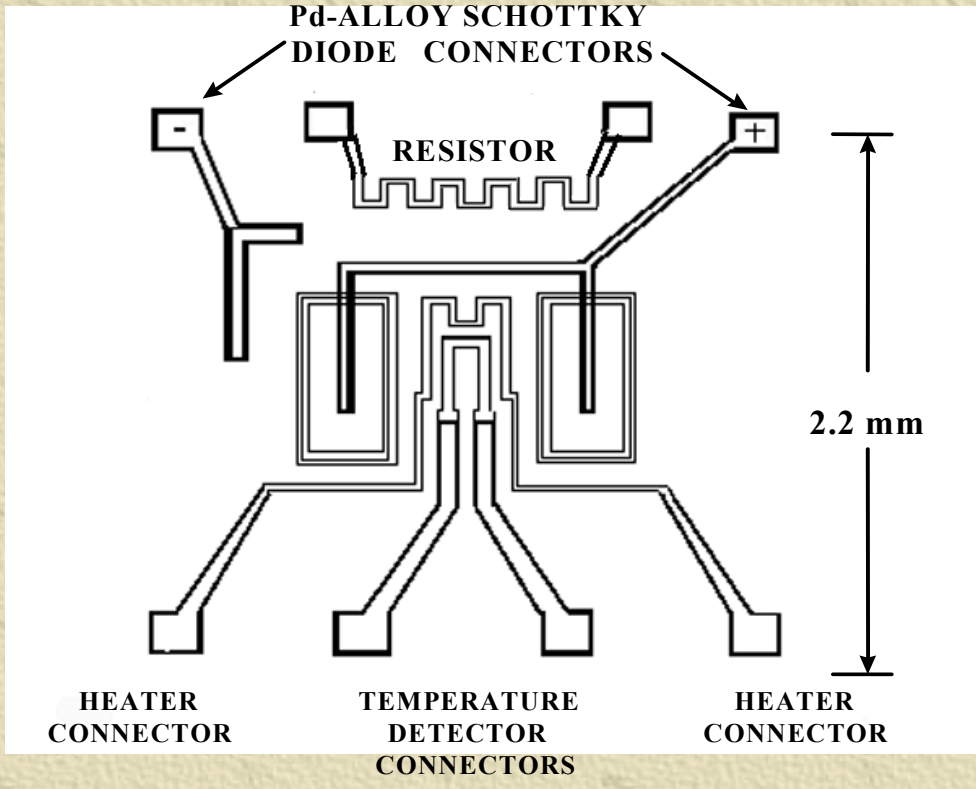


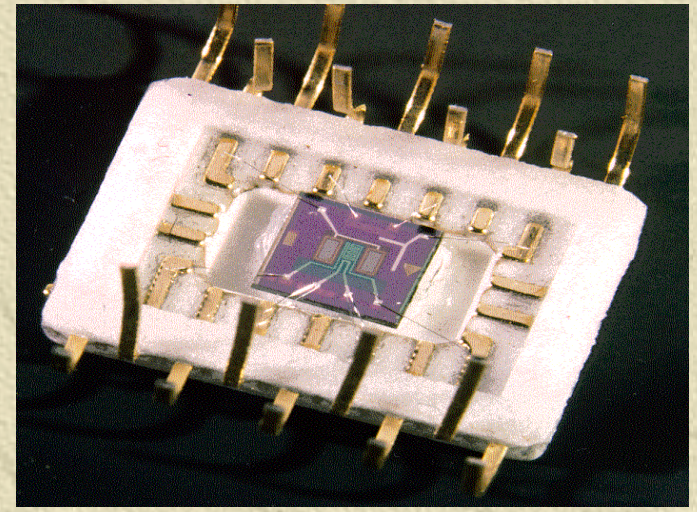


HYDROGEN EAK SENSOR TECHNOLOGY

SBIR / Phase-II / Makel

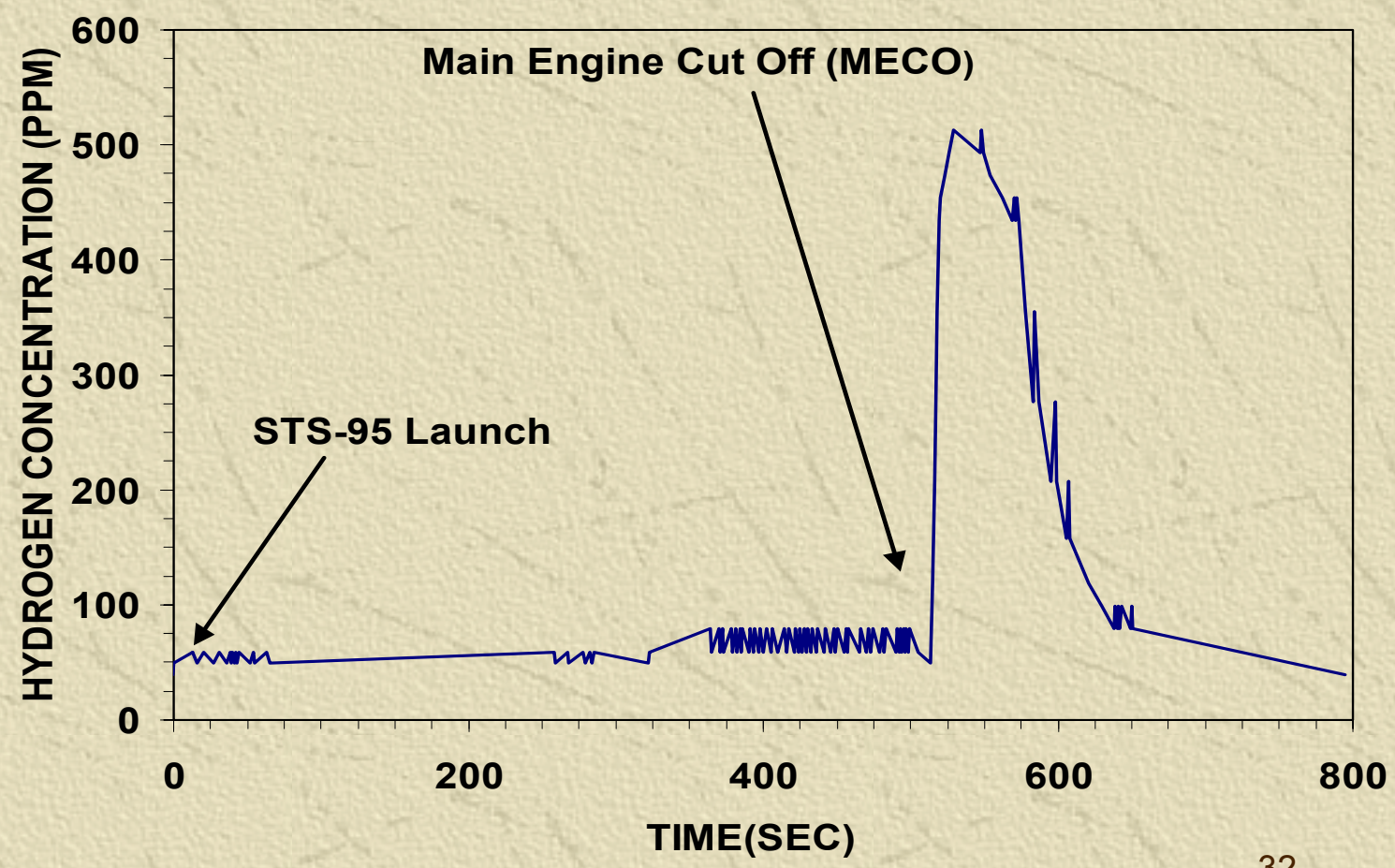
WIDE CONCENTRATION RANGE HYDROGEN SENSOR DESIGN



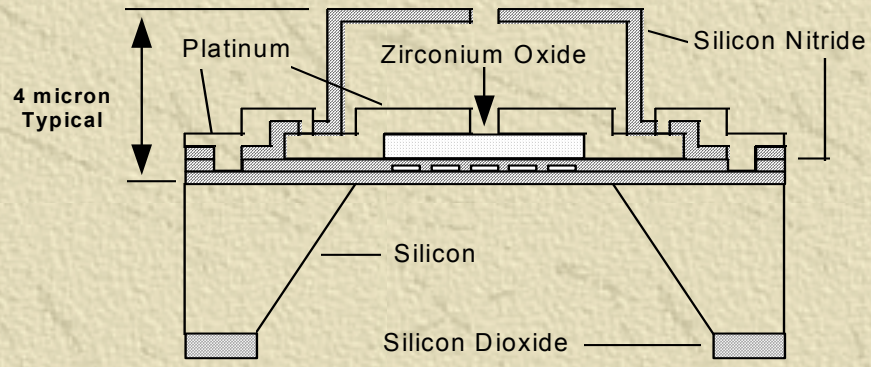


SBIR / Phase-II / Makel

STS-95 Hydrogen Sensor Flight Data



SBIR / Phase-II / Makel



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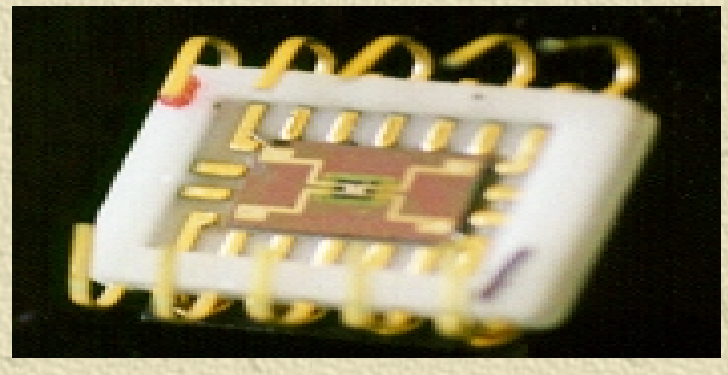
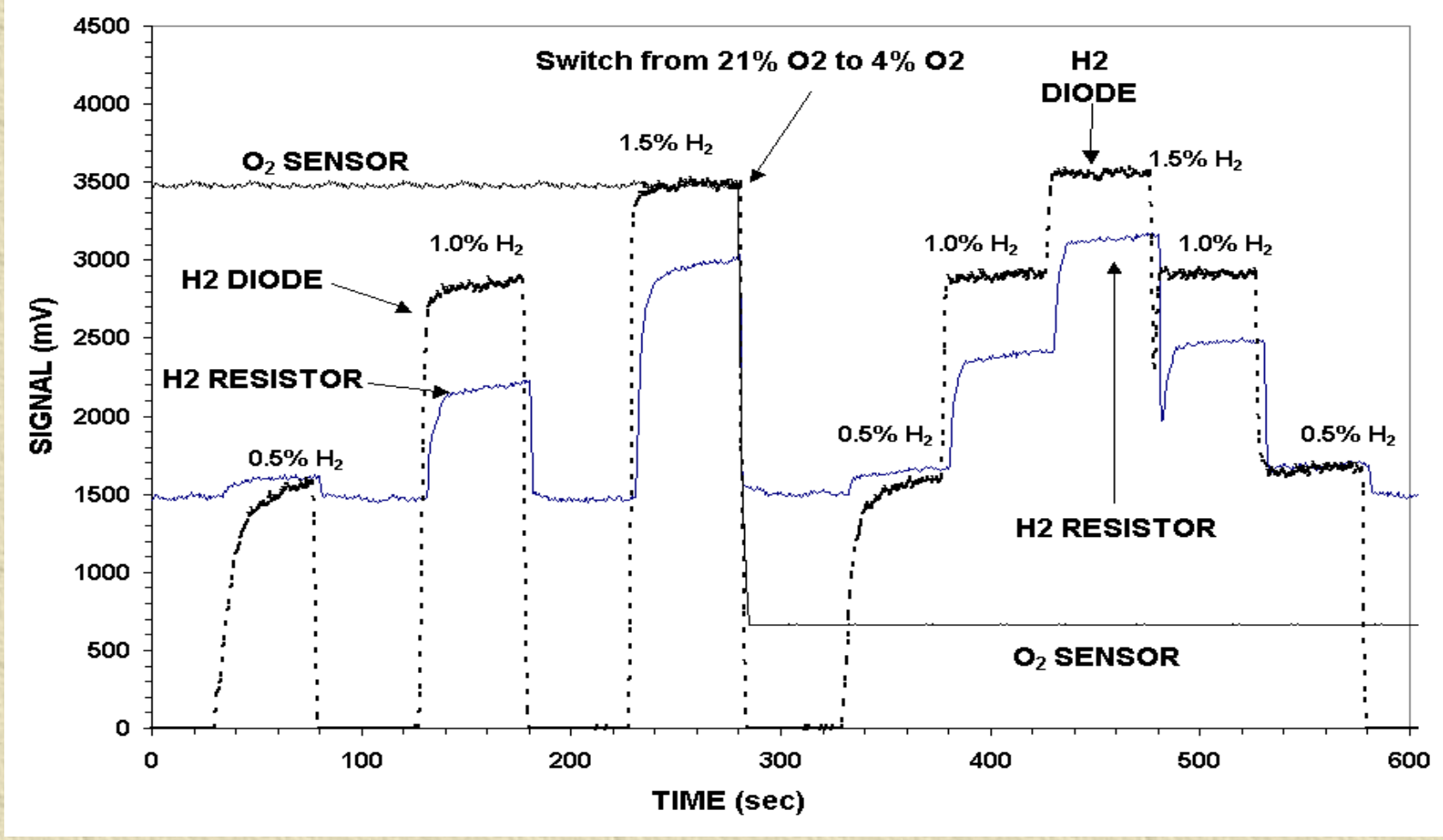


ZrO2 Oxygen Sensor

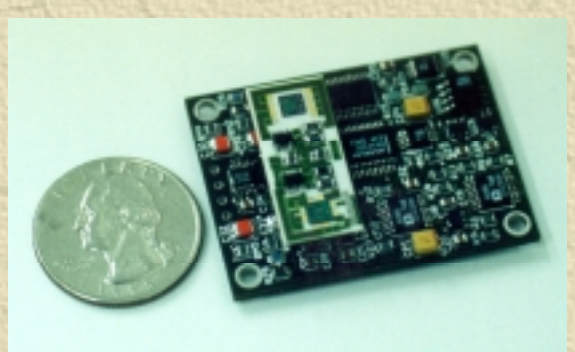
- **MICROFABRICATED AND MICROMACHINED FOR MINIMAL SIZE, WEIGHT AND POWER CONSUMPTION (LESS THAN 2 W FOR 600 C OPERATION)**
- **AMPEROMETRIC OPERATION ALLOWS MEASUREMENT OF OXYGEN OVER A WIDE CONCENTRATION RANGE (0-100%)**
- **CHAMBER STRUCTURE CONTROLS OXYGEN DIFFUSION RATE**
- **INCORPORATION OF OXYGEN SENSOR WITH OTHER SENSORS (E.G. HYDROGEN) IN THE SAME PACKAGE PLANNED**

SBIR / Phase-II / Makel

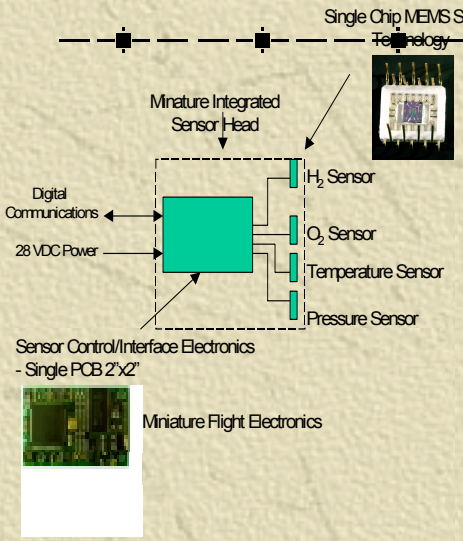


2nd Gen / Makel

- Focus is Ultra Miniaturization of Leak Detection Systems on 2nd Gen Vehicles
- Team is NASA GRC, NASA KSC, Makel Engineering, and Case Western Reserve University
- Provide Simultaneous Measurement of Fuel and Oxidizer
  - Hydrocarbon, Oxygen, and Hydrogen Sensors
- Reduce Power Consumption From 5W to approximately 100mW
  - enable battery or use of other low power source
- Reduce Size Of Entire Sensor Module To Postage Stamp Size
  - enable large number of low cost sensors to be used
  - enable sensors to be incorporated into structures (composite valves, supports etc.)
- Accomplishments - First Generation of Miniaturization Completed - Testing Being Conducted at KSC



2nd Gen / Makel

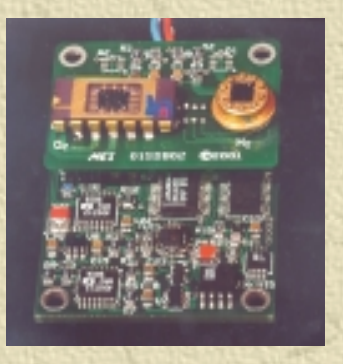


Oxygen Sensor

Hydrogen Sensor

- **Develop a multi-parameter smart sensor suitable for launch applications.**
  - **Hydrogen, Oxygen, Pressure, and Temperature**
- **Produce stand alone sensors suitable for future flight experiment or use on facilities**
- **Tasks accomplished include:**
  - **thin film sensor optimization for hydrogen and oxygen**
  - **development of data logger module and flight power supply to enable autonomous flight experiments (i.e. No central data logger needed like IVHM experiments on STS-95 and STS-96)**
  - **fabrication of prototypes to be delivered to NASA KSC in 2002**
- **NASA Applications Include**
  - **Flight Sensor For Space Shuttle**
  - **Launch Pad Facility Sensor**
  - **Sensor for Grab Bottle Replacement**
- **Commercial Spin Off of Product Being Tested by Non-NASA Customers**
  - **PEM Fuel Cell Monitoring**
  - **Fuel Cell Vehicle Leak Detection**

Temp Sensor connector (on back of board)



Pressure Sensor

SBIR / Phase-I / SW Sciences

- South West Sciences
  - Special Time of Flight