Sensor Development for Harsh Environments

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SECA Core Technology Program

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Sensors Required for High Performance - To Improve Reliability and Control

- Goals for Sensor and Controls
  - Increase operational efficiency
  - Reduce emissions
  - Lower operating costs
  - Accelerate time to full-scale commercial implementation
- Numerous challenges exist
  - Extremely confined spaces
  - Harsh oxidizing and reducing environments
  - High temperatures (600 to 900 ^{0} C)
  - High electrical fields
  - Material issues (corrosion, deposition, etc.)
  - Long service life (5,000 hours in transportation; 40,000 hours for fixed site)

Sensor Measurement Requirements Are Very Challenging

- Flows (0 - 2 liters/min)
- Pressure (0 - 5 psig)
- Gaseous composition: steam, CO, CO_2, H_2, O_2, H_2S, CH_x (0.1% up to 100%)
- Sulfur (ppm level to a few percent)
- Accuracy to within 1% of sensing range
- Best if non-intrusive or embedded in materials

SOFC Sensor Requirements Similar to CIDI/SIDI Engine Needs

- Items to be measured: O_2, CH_x, CO, Sulfur, Temperature, flow
- Environmental and operational conditions: temperature range essentially the same, low-cost, limited space, robust, accurate, high sensitivity, and low/no maintenance

National Labs have experience with auto industry in measurement technology development

National Laboratories Are Well-Suited for Sensor Development

- Multidisciplinary approach required to develop sensor systems
  - fundamental physics, material and joining sciences, measurement science, electronics, packaging, integration, and information/knowledge extraction
- History of dealing with harsh processing environments
  - radiation, corrosive chemicals, high temperatures, precision measurement and controls, safety and security

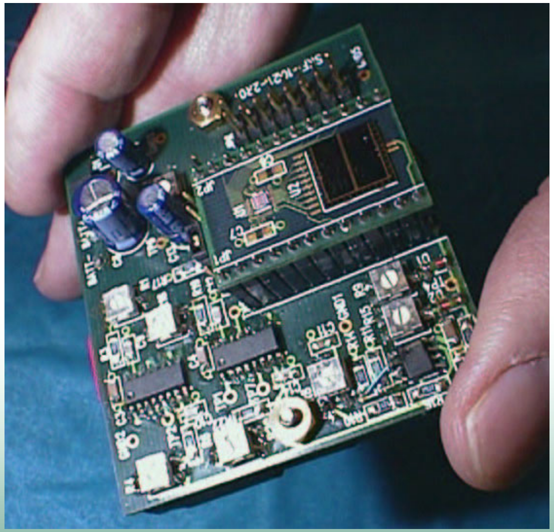
Sensor Development Programs Underway at Several National Labs

- **LANL** - electrochemical sensors for HC and CO gases, zironia O_2 sensor, ultrasonic sensor for pressure
- **SNL** - acoustic wave HC gas sensor, micromachined catalytic gas sensors (CO, H_2, HCs), H_2 chemical resistance and optical sensor, MEMS pressure sensors
- **ANL** - HC ion mobility sensor, microwave sensor for NO_X, acoustic and SAW for exhaust gas, flow, and temperature
- **PNNL** - O_2 and NO_X sensors

Most of these sensors operate at temperatures < 500^0C

ORNL's Diversity and Multi-program Nature Results in Excellent Resources for Sensor Development

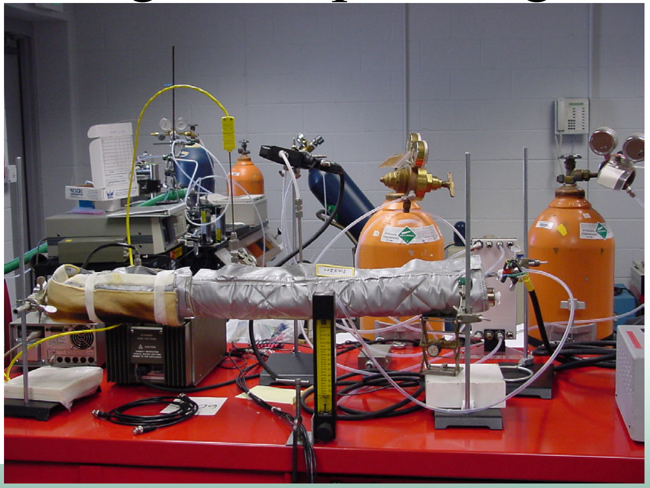
- Over 150 professionals in measurement science
  - engineers, physicists, material scientists, chemists, electro-optics researchers, and metrologists
- Advanced analog and digital electronics (ASICs, microprocessors, low-power designs, microbatteries
- Signal and image processing for data flow, information, and intelligence
- Material synthesis & characterization for harsh environments
- Systems engineering for packaging, miniaturization, integration, and sensor networks (optical and wireless)



ORNL's Diversity and Multi-program Nature Results in Excellent Resources for Sensor Development (continued)

- Facilities for developing, prototyping, testing, and characterizing sensor concepts, robustness, and sensitivities
  - micro and nanofabrication laboratories (multilayer clean room sensor fab/1000 sensors per year)
  - materials (catalysts) synthesis and characterization facilities
  - testing and characterization facilities (environmental effects including high temperature and multi- or single component gas mixtures)

Staff, experience, and labs create technology development path for robust, low-cost ($10s) sensor systems



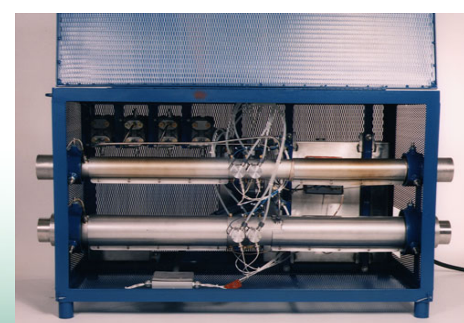
ORNL Has Developed Harsh Environment Sensor Systems

CBMS

- Vehicle exhaust gas flowmeter (650^{0}C, 150 to 1 range, fast response, low ΔP)
- Liquid film probes (800^{0}C, severe thermal shock)
- Drill bit monitor (high temp electronics)
- Chem/Bio Mass Spectrometer (radiation, vehicle operation, EMP, low power)
- Extraction of information from very noisy signals

Liquid film probe

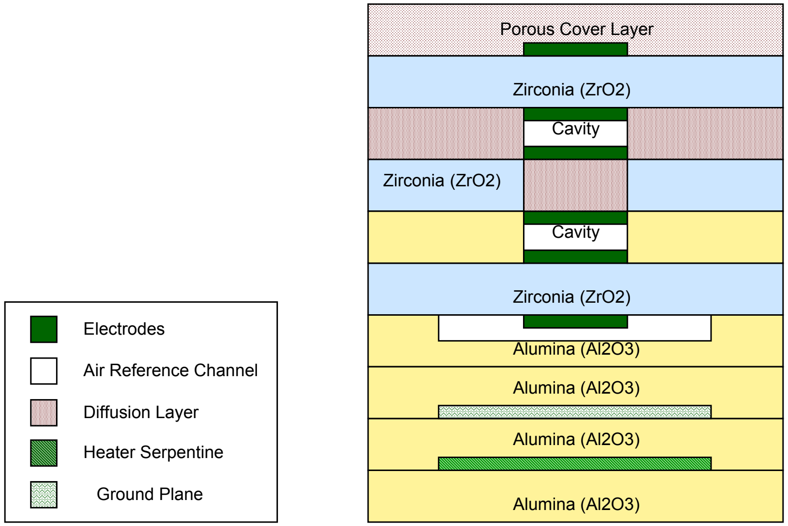
Vehicle Exhaust Flow



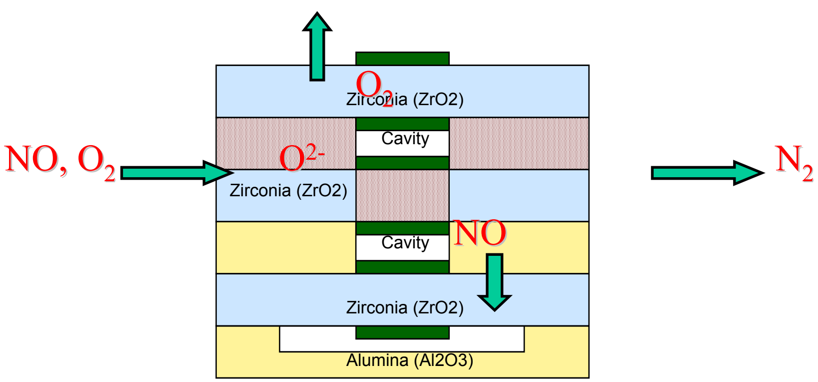
ORNL Sensor Development for Automotive Applications that May Fit SOFCs

- NO_X, O_2, and NH_4 sensor development in progress
  - planar O_2 sensor developed with output proportional to partial pressure; response time diffusion barrier/geometry dependent
  - low-cost NO_X demonstrated to 400^0C; commercialization partner on board
  - resistive mixed potential sensors for NO_X, NH_4, H_2S, hydrocarbons with potential for lower cost and easier to produce

ORNL NO_x Sensor Development



Sensor Type #1 (Gasoline lean burn engine)
Sensitivity: 100-200 ppm (potential lower detection limit for diagnostics)
Accuracy: +/- 20 ppm
Response Time: < 1 sec (0-90% full scale)
NO/NO_2: equally sensitive to NO and NO_2
Concerns: sulfur



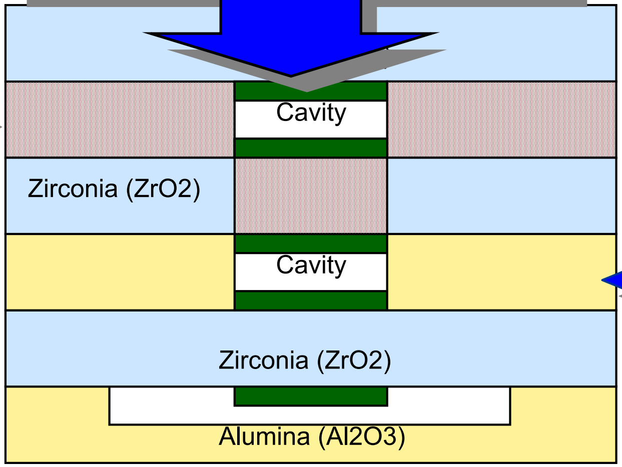
Sensor Type #2 (Diesel application with urea)
Sensitivity: 20-300 ppm
Accuracy: +/- 20ppm
Response Time: < 1sec (0-90% full scale)
NO/NO_2: separately measure NO and NO_2
Concerns: soot, sulfur and urea(NH_3)

NOx Sensor Development at ORNL

Non noble metal electrodes to eliminate NO_x catalysis

Porous materials to control diffusion of exhaust gases

Developed and in production!



Low dielectric constant insulators to reduce cross talk

Prototype materials developed

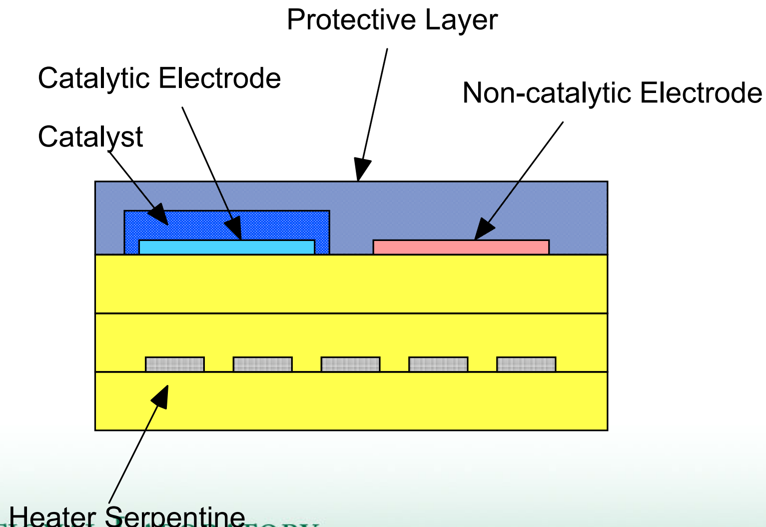
Modeling of sintering processes in multilayer bodies composed of materials with differing properties.

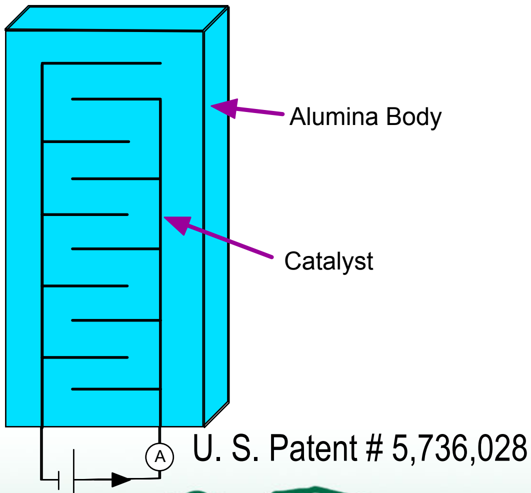
Several issues need to be resolved before NOx sensors can be commercialized

Primary Issues	Secondary Issues
• **Response time** (<500 ms) – monitoring vs control • **Sensitivity** – 10 ppm NO – small signal (~10nA/ppm) • packaging • electronics • **Cost**	• **Durability** – drift – aging • **Poisoning** • **Selectivity** – NO vs NO_2 – NH_3, O_2, H_2O, and HC interference

Mixed Potential Sensors for High-Temperature Sensing

- Current development indicates need for resistive mixed-potential sensors for:
  - NO_x, NH_4, H_2S, hydrocarbons
- These sensors offer: simpler designs and electronics, large signals, reduced cost
- However, they must operate at reduced temperatures (<600°C) and they may have prohibitively long response times





UT-BATTELLE

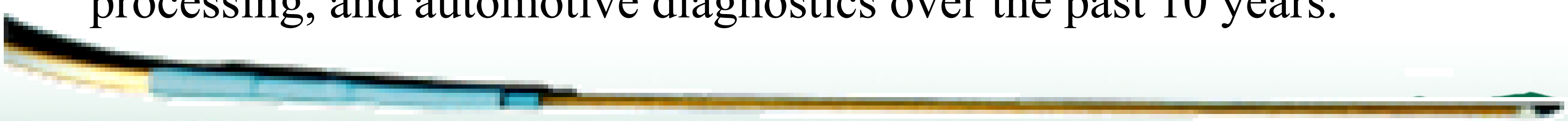
Several New Sensor Concepts Are Exciting Possibilities for Fuel Cells

- CO sensor based on oxidization - measurement of heat evolved leads to amount of CO present
- Fiber-optic thermophosphor temperature sensor based on fluorescence decay being proportional to temperature
- Micro-size laser absorption measurement systems using long wave IR for gas spectroscopy
- Microcantilever arrayed measurement system for gas detection
- H_2S sensor based on novel S conducting electrolyte

Fiber-Optic Coupled Phosphor Thermometer Offers Highly Reliable, Accurate Temperature Measurements

Objective:

- Development of a reliable, accurate, low-cost temperature sensor for monitoring and control of fuel cell systems
- YAG fiber-optic probe developed with high resistivity to corrosion and erosion to extend probe life
- Design robust mechanical interface to couple sensor to fuel cell
- Provide high sensitivity and quality signal conditioning electronics
- Develop a drift-free, high accuracy, robust optical thermometry system
- Sensor consists of a single crystal YAG fiber with a phosphor grown directly on the fiber tip
- Phosphor thermometry has been demonstrated by ORNL for turbine, steel processing, and automotive diagnostics over the past 10 years.

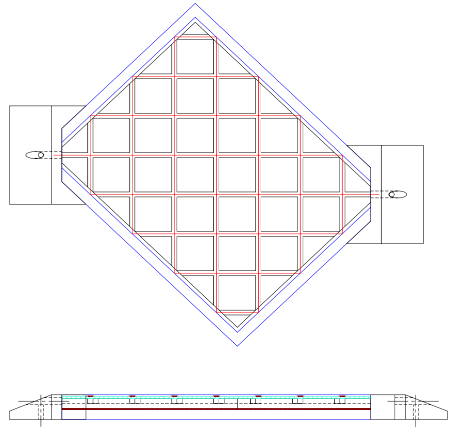


Micro-optic temperature sensor

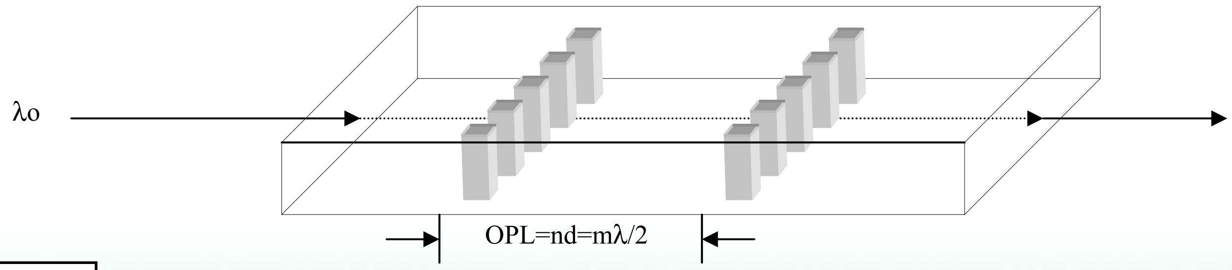
Hyper-sprectral, Longitudinal Integrated Resonator Gas Sensor on a Chip

<u>Objective:</u>

- Develop integrated single chip gas spectroscopy system
- Measure CO, ammonia, H_2S, and SO_X to better control fuel cells for enhanced performance
- MEMS fabrication of wristwatch size CO_2 laser and folded cavity approach for gas sampling cells
- Integrated laser and sampling cell to provide sensor-on-a-chip



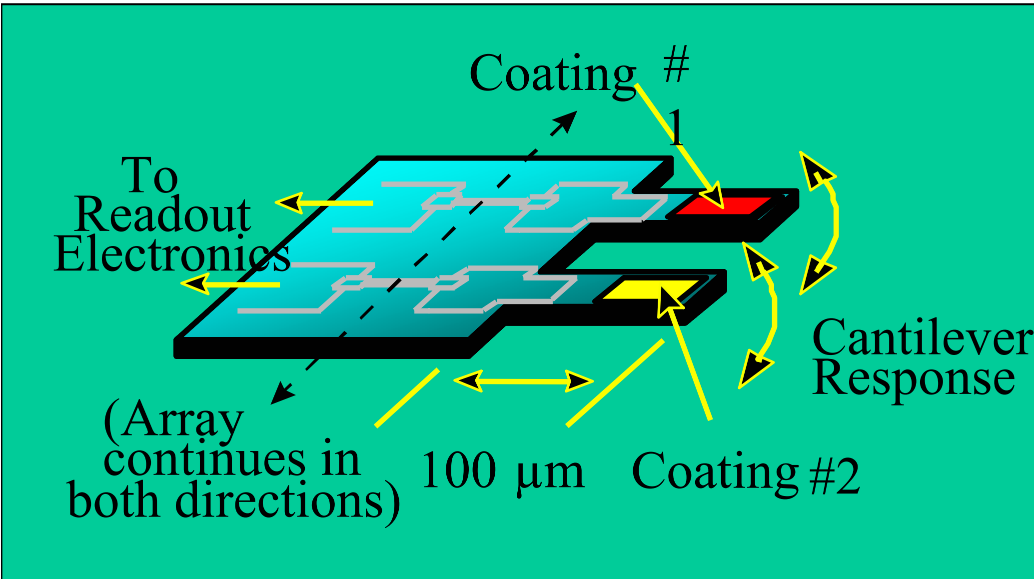
Laser

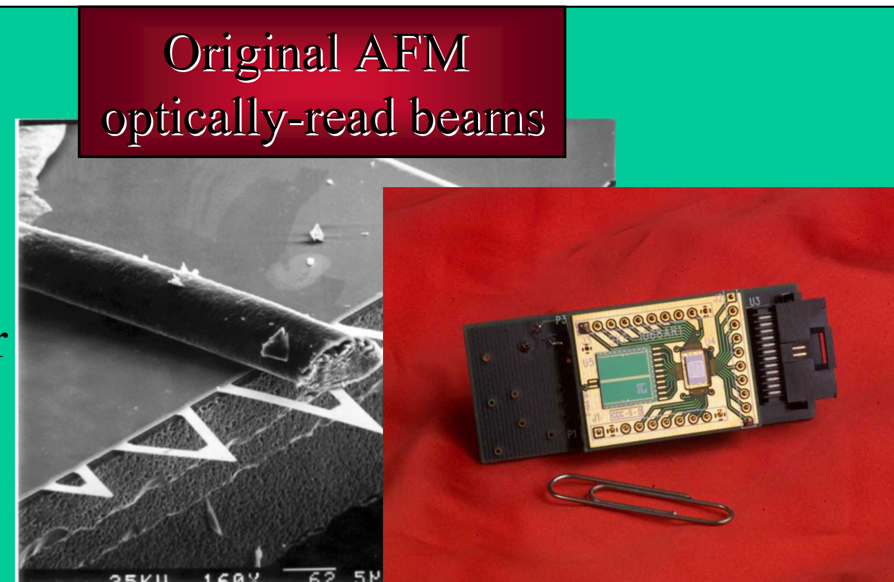


Folded Cavity

MEMS-Based Hydrogen Sensors

- Enhance energy efficiency and safety of fuel cell fuel quality and leak detection
- Provide low-cost hydrogen sensor for fuel-cell process control and leak monitoring
- Develop platform that is expandable to sensing other gases such as CO and SO_2
- Utilize an economical micro-electro-mechanical system (MEMS) sensor developed for hydrogen sensing
- Demonstrated high-performance, stable output at temperatures and environmental conditions
- Develop reliable, sensitive low-cost electronic signal conditioning and readout





National Labs Well-Positioned for Developing Sensors for Harsh Environments

- Sensors for SOFCs are essential and development is very challenging
- National Labs have multidisciplined expertise and experience to address the issues - large cadre of experts in all aspects of measurement systems from the sensor concept, to materials & fabrication, microelectronics, signal processing, packaging, testing & characterization, and overall integration