Micro-Machined Thin Film H_2 Gas Sensors

DOE Hydrogen and Fuel Cells
2003 Annual Merit Review

ATMI

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Outline

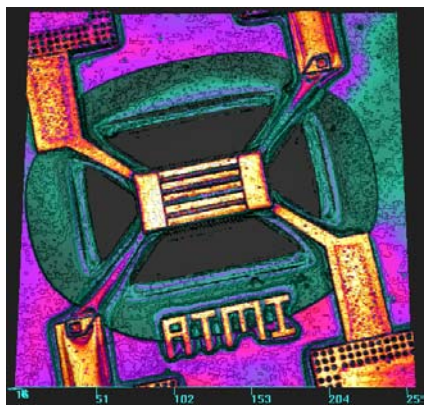
- Introduction
- Approach
- Project Timeline
  - Overall and FY2003
- Accomplishments/Progress
  - Focus on Understanding and Yield
- Communication/Collaborations
- Future Work

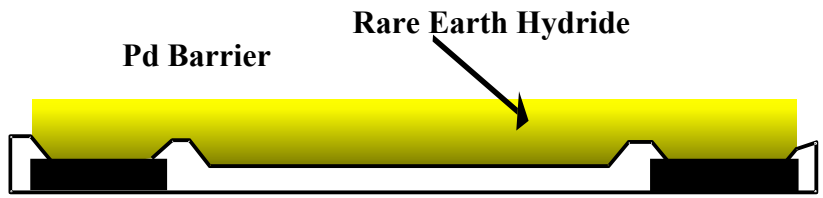
Introduction

- Project Relevance
  - **2002 National Hydrogen Energy Roadmap**
    - Delivery – Efforts should focus on the development of better components for existing delivery systems, including **hydrogen *sensors***…
    - Storage – Emerging hydrogen applications requires … "smart" tanks with **integrated or embedded *sensors***, …
    - Conversion – Other key research needs include … ***more*** **durable and lower-cost *sensors***…
    - Applications – Development needs include **low-cost, fast-response, and low-power consumption *sensors***…

Goals and Approach

- Project Goals
  - Demonstrate the capabilities of micromachined H_2 sensors
  - Develop an understanding of their performance
  - Critically evaluate the utility and viability of this technology for life safety and processing monitoring
- Approach
  - MEMS based platform coupled with multilayer hydride films
  - Thermally controlled chemi-resistive transduction

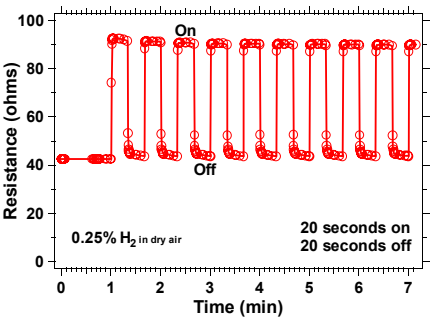


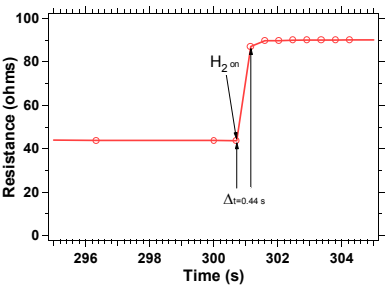


Overall Project Progression

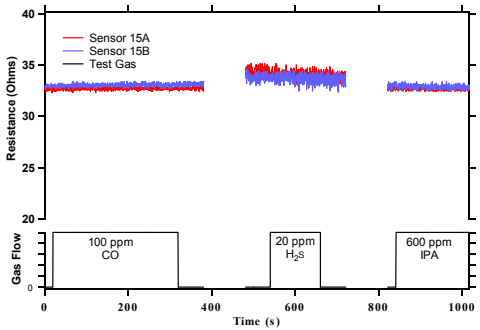
FY2000 FY2001/02 FY2003 FY2004

Proof of Concept





Feasibility Showstoppers



Field Testing Technology Extension

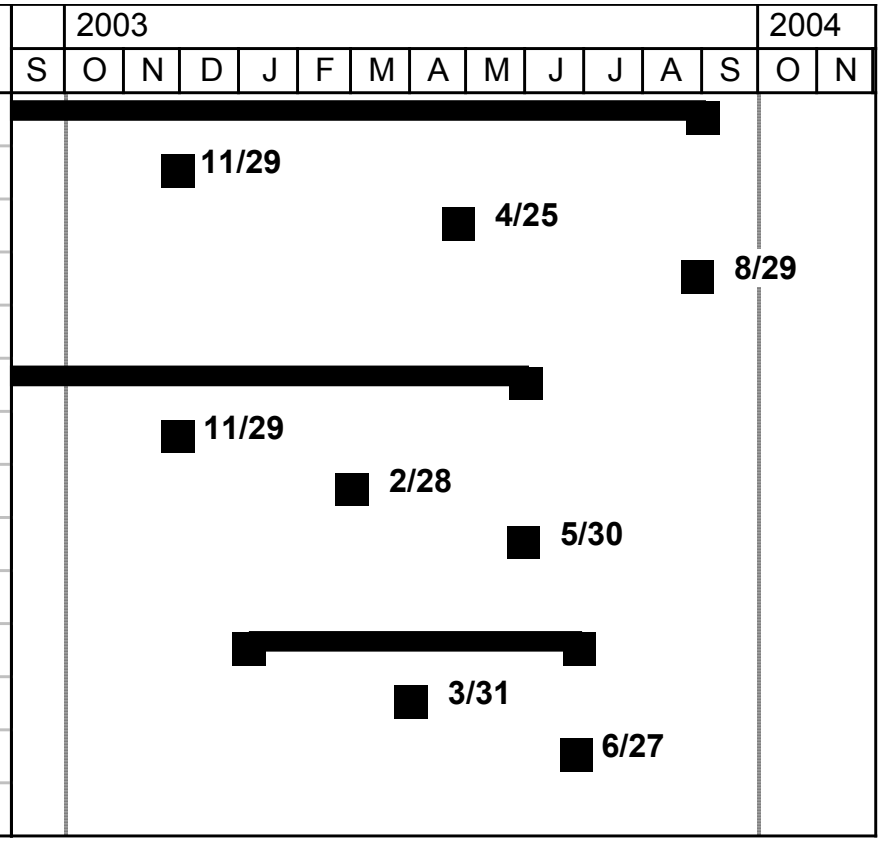
Reproducibility/Scale up
Fundamental Understanding
Systems Development
New Device Innovation

AATMI

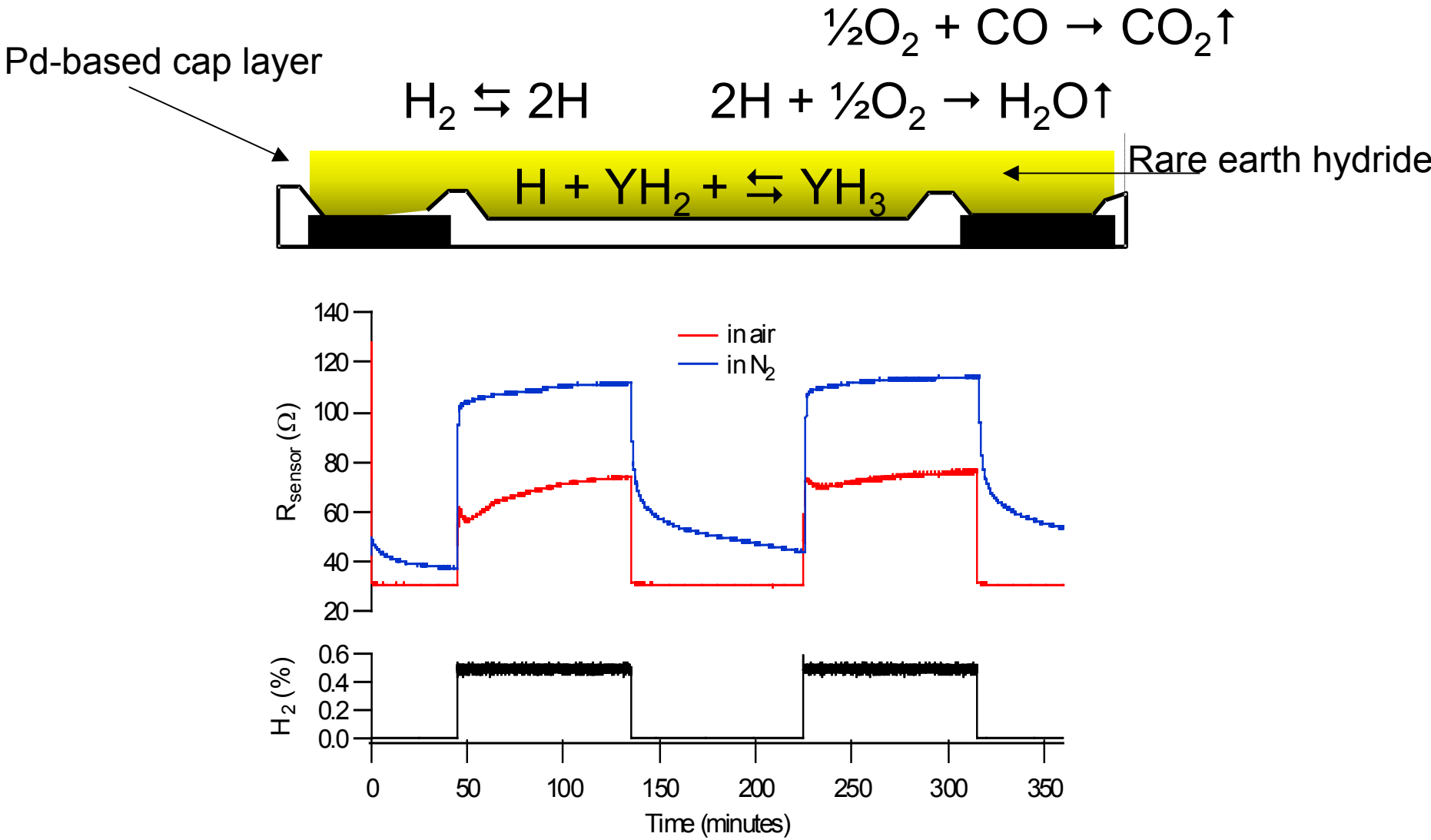
Materials Lifecycle Solutions

FY 2003 Timeline and Milestones

ID	Task Name
1	**Fabrication and Process Control**
2	Establish Process of Record
3	Evluate of Novel Process Step(s)
4	Optimize Fabrication Process
5	
6	**Sensor Characterization and Analysis**
7	Implement Quality Control Protocol
8	Characterize Sensor Device & Materials
9	Design Application-Specific Sensors
10	
11	**Systems Development**
12	Finalize Package Designs
13	Finalize Signal Conditioning Circuitry
14	

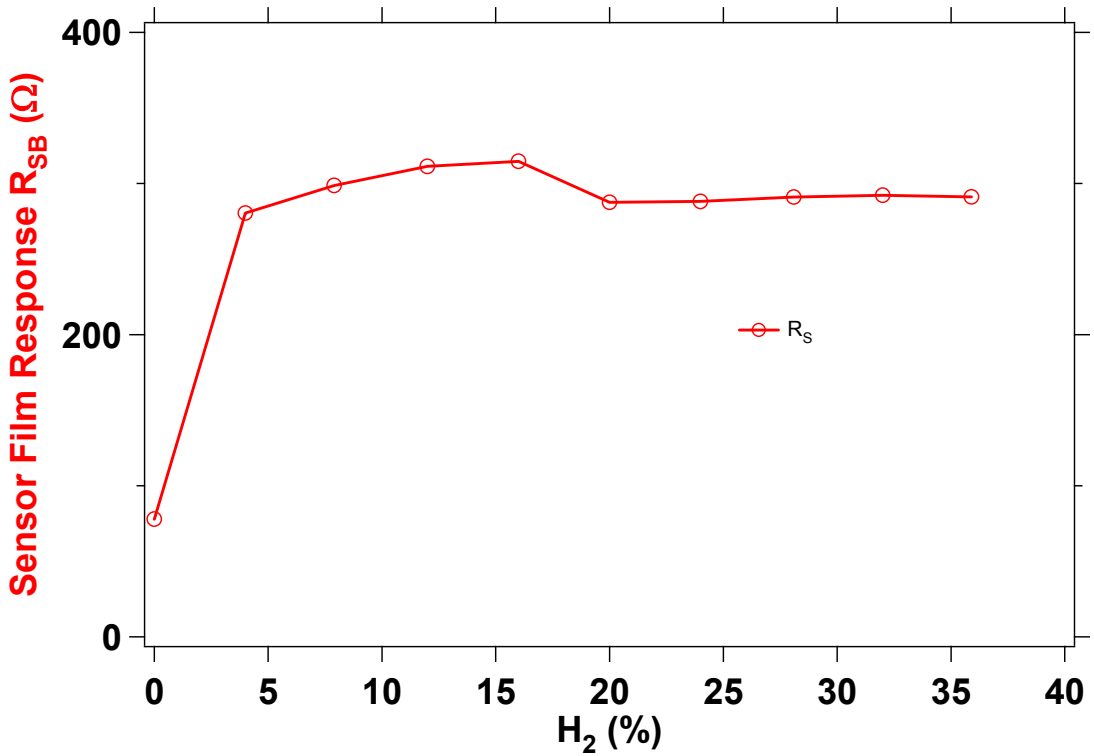


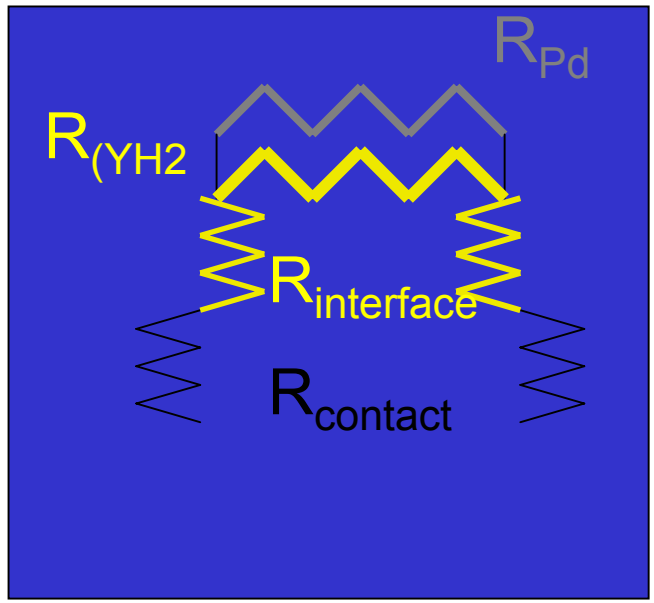
Device Model:
Chemical, Electrical, Mechanical



Device Model:
Chemical, Electrical, Mechanical

$$R_{sensor} = 2\,R_{contact} + 2\,R_{interface} + R_{Pd}//R_{(YH2 + \leftrightarrows YH3)}$$





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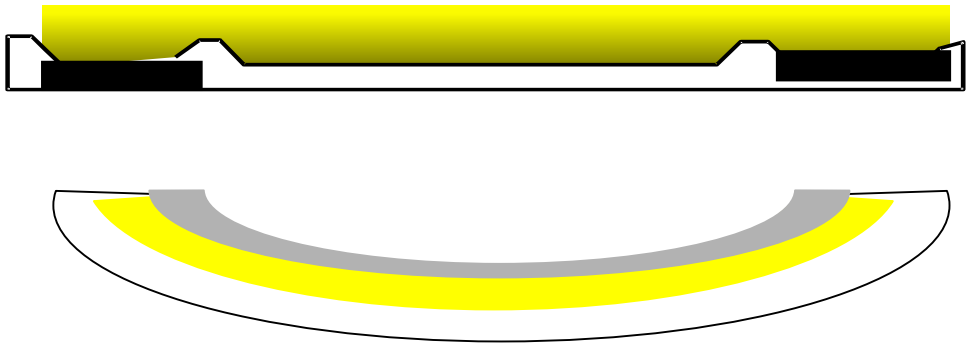
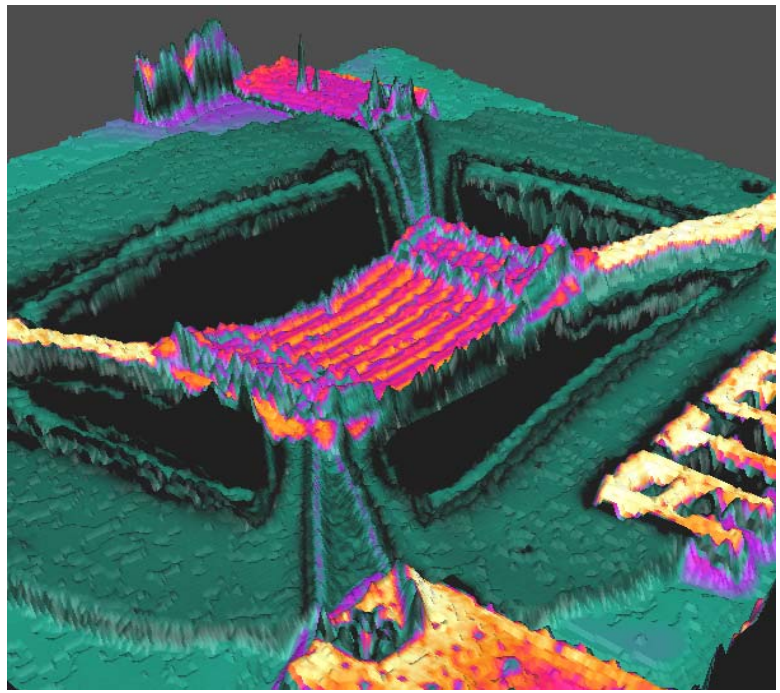
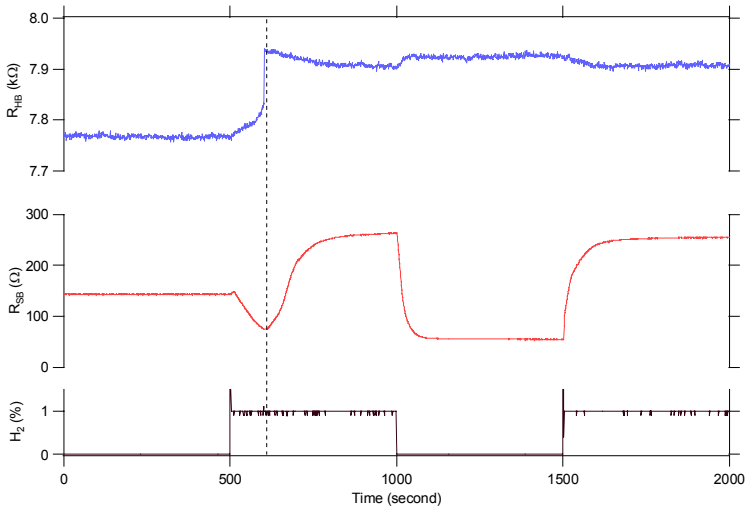
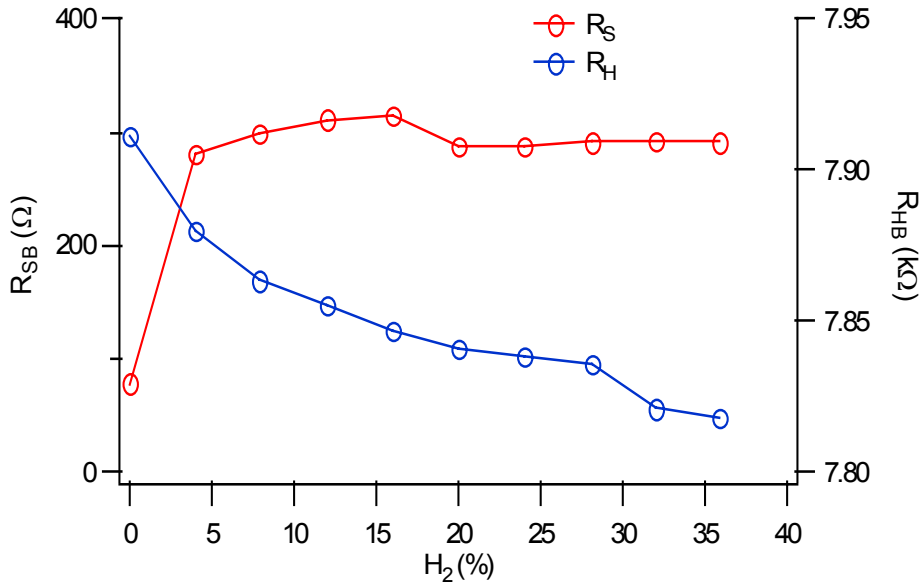




- Volume of YHx changes by 15% from x = 2 to x = 3,
- Confocal Microscopy capability enabled measurement of bending
- Poly Silicon resistance is modulated via piezo-resistive effect
  - "Strain Gauge H_2 sensor" Pat. Pending

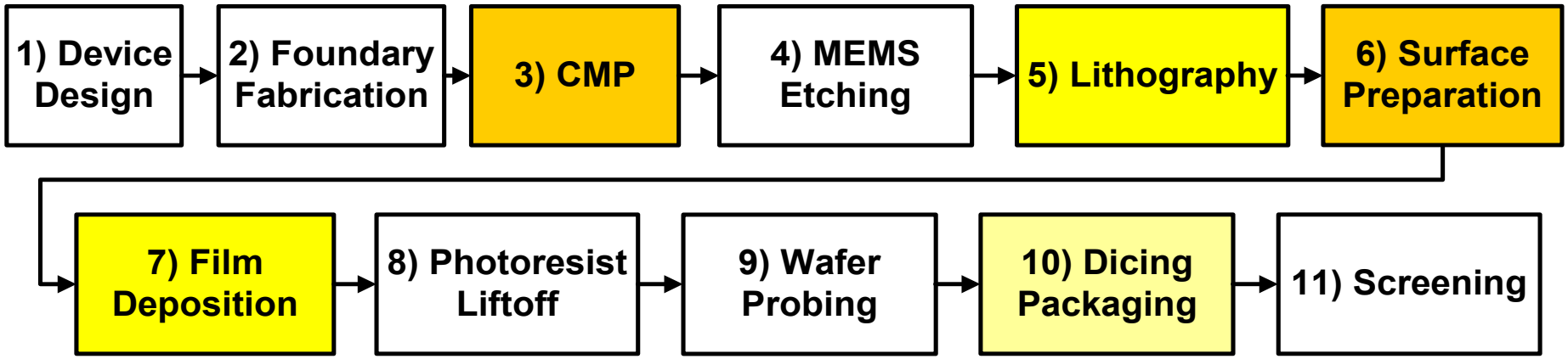
New Mechanical Transduction Data





- Potential for significant cost reduction
  - 2 wire sensor vs 4 wire sensor
  - Fewer layers
- Dual Transduction Cap

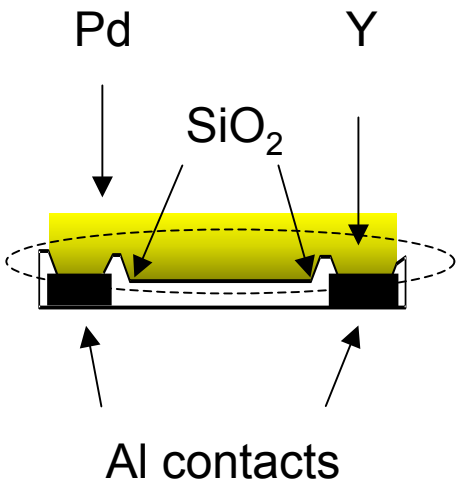
Fabrication/Process Control: Process of Record

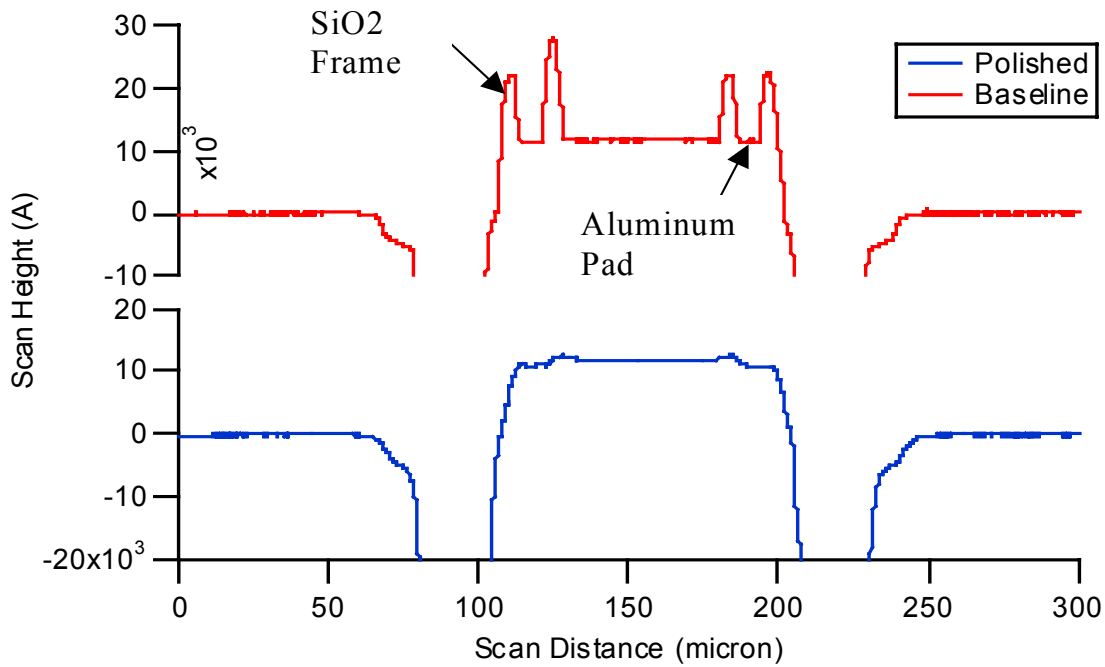


11 Total Process Steps with 110 Variables

- POR forms foundation for continuous process improvement
  - Currently on V7.1
- Designed experiments and detailed process analysis focused on critical steps

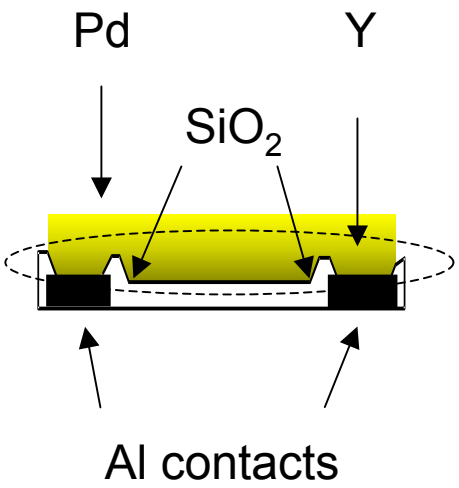
Fabrication/Process Control: Chemical Mechanical Polishing

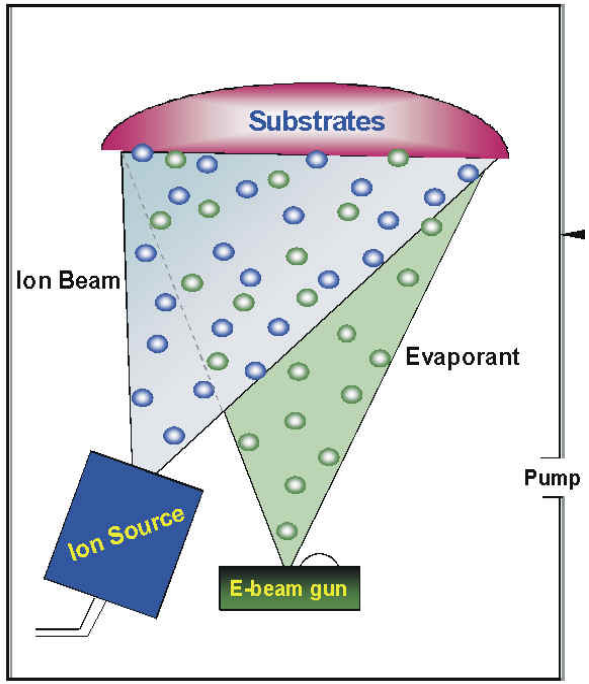




- SiO_2 frame height can be 5 to10X functional film thickness
- Surface preparation reduces frame height and improves uniformity and yield

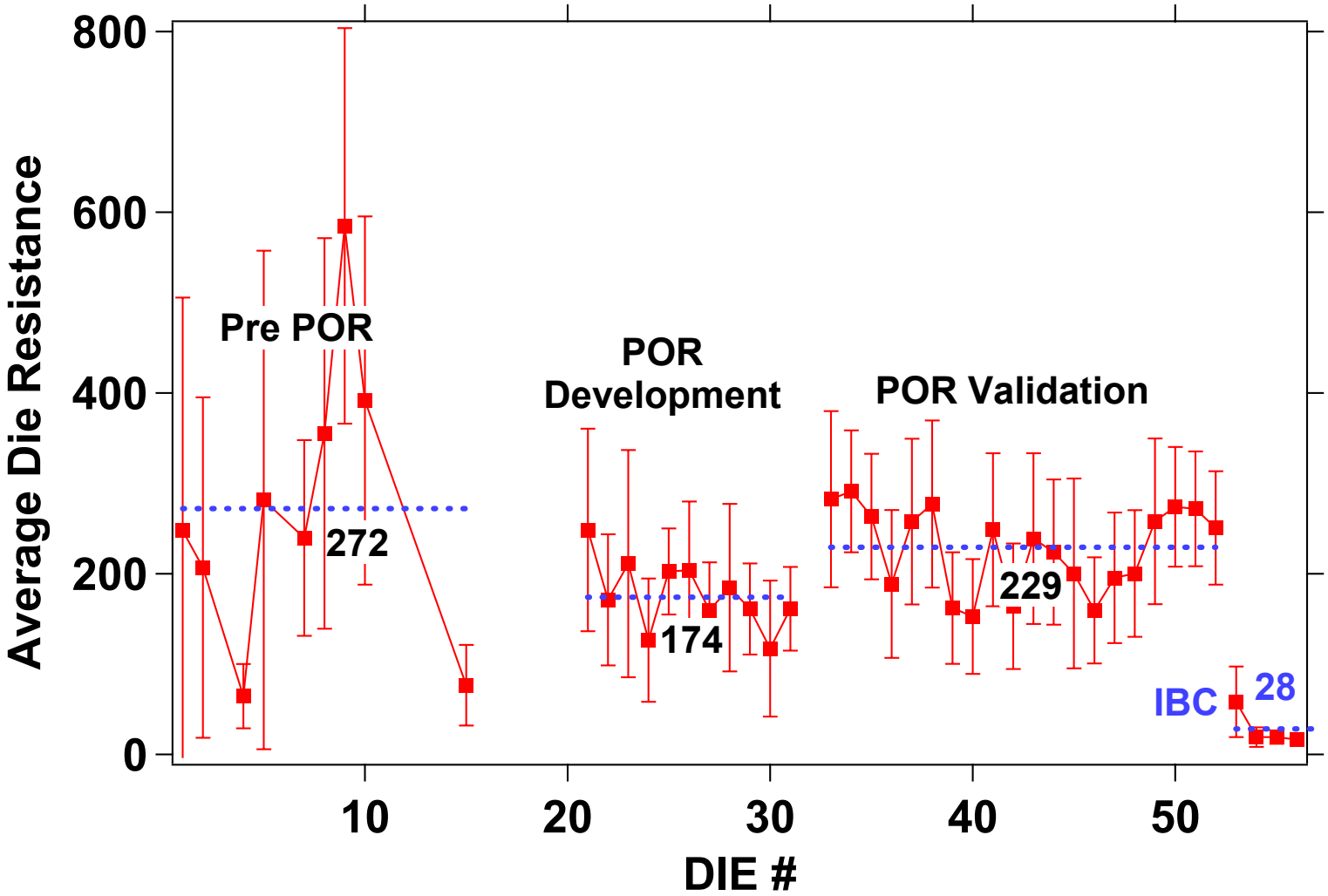
Fabrication/Process Control: Ion Beam Cleaning





- *In situ* contact clean prevents Al contact surface re-oxidization and reduces contact resistance

Fabrication/Process Control: Results for Die Resistances



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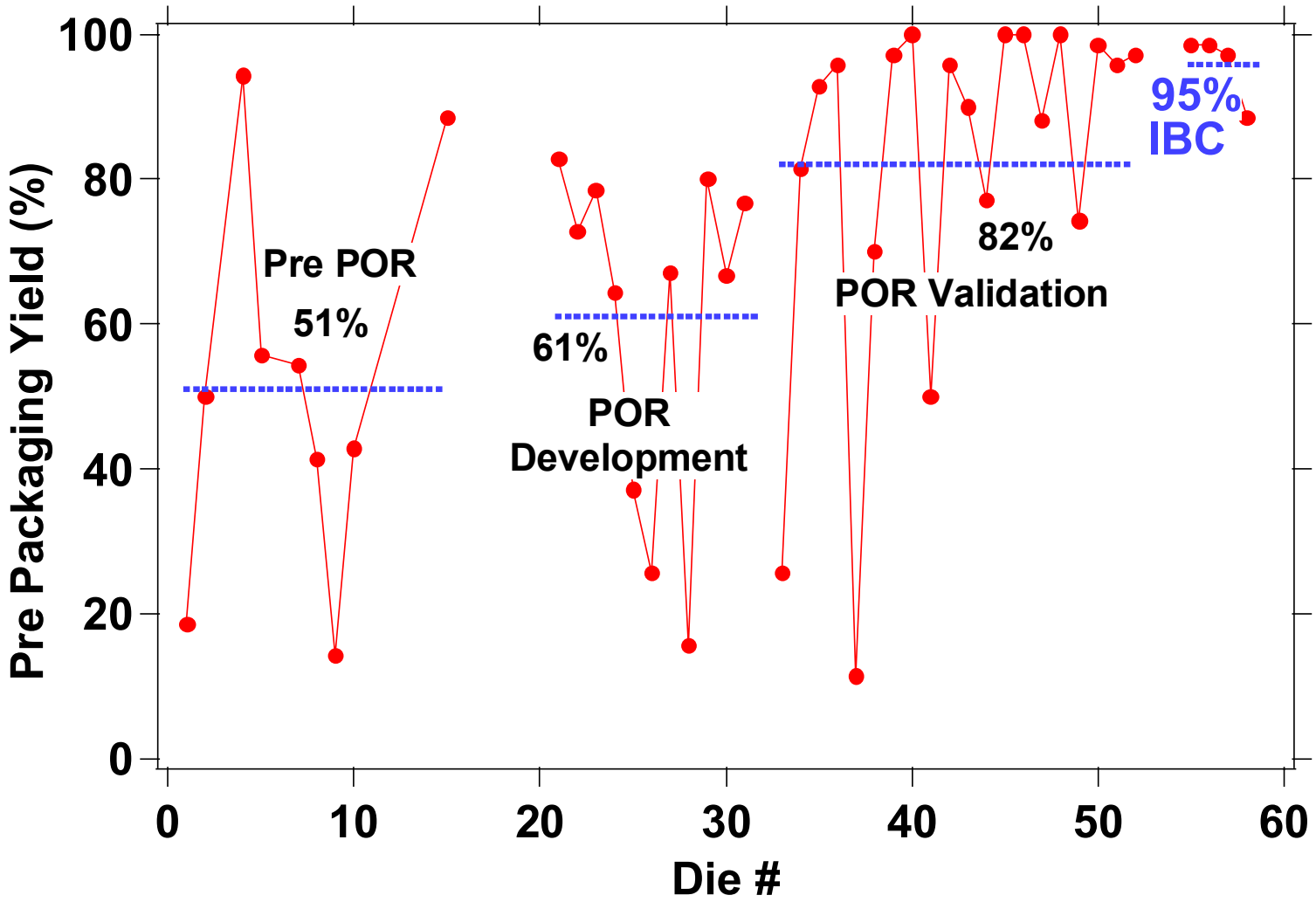
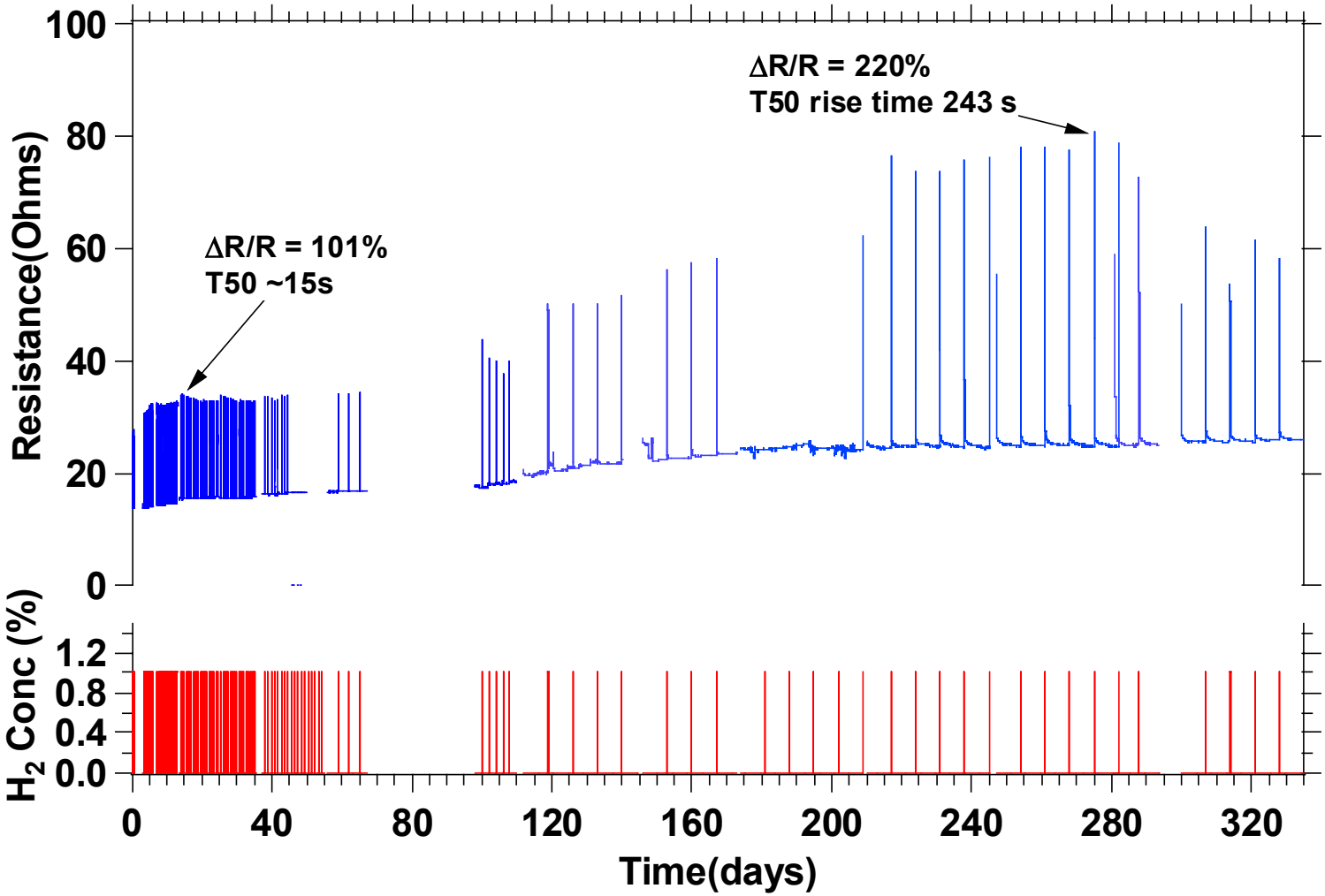


Systems Development: Long Term Data



Systems Development– Packaging and Signal Conditioning

- Signal Conditioning Board
  - Dual channels,PIC processor-based, on-board calibration, RS 232 and Analog out
- Self Contained Data Logging

Communication/Collaborations

- Publications and Presentations
  - "MEMS Based H_2 Gas Sensors", submitted *Journal of Electrochemical Society*
  - "Microelectronic H_2 sensing for Emerging Sensing", CMOC 2003
- Issued Patents
  - G. Bhandari and T.H. Baum, "Hydrogen sensor utilizing rare earth metal thin film detection element," U.S. Patent 6,006,582 (1999).
  - F. DiMeo and G. Bhandari, "Micro-machined thin film hydrogen gas sensor, and method of making and using the same," U.S. Patent 6,265,222 (2001).
- Allowed
  - F. DiMeo and T. Baum "Micro-Machined Thin Film Sensor Arrays For The Detection Of H2, NH3, And Sulfur Containing Gases, And Method Of Making And Using The Same"
- Pending
  - F. DiMeo, P. Chen, " Rare Earth Metal Sensor"
  - I.-S. Chen and F. DiMeo, "Micro-machined piezo-resistive gas sensor, and method of making the same,"
- Collaborations
  - ATMI Life Safety Systems, ATMI GaN Products, UTC Fuel Cells

Future Work: Complete Program Milestones

- Fabrication and process control
  - Continuous improvement and refinement
- Sensor characterization
  - Re-examine optimal operation conditions based on improved fabrication techniques
  - Explore new piezo-resistive device structures
- Systems
  - Complete datalogging prototype
  - Deploy prototypes internally at ATMI

Summary/Accomplishments

- Demonstrated CMOS based MEMS based H_2 Sensors with Sub second response time
- Demonstrated hydrogen selectivity
  - no response to CO, H_2S, IPA
- Engineered sensors to operate with low power (<6mW) consumption, enabling mobile applications
- Developed an understanding of sensor behavior
  - Basic electrical device model developed
  - Demonstrated novel piezo-resistive H_2 sensor

This technology looks promising for meeting the sensing challenges presented by emerging H_2 applications!