Chemical Microsensor Development for Aerospace Applications

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Chemical Sensor Development at NASA GRC

- **Microsensors and platforms**
  - $\text{H}_2$, $\text{CH}_4$, $\text{C}_2\text{H}_4$, $\text{C}_3\text{H}_6$, $\text{CO}_2$, $\text{CO}$, $\text{O}_2$, NOx, $\text{N}_2\text{H}_4$, HCl, HCN, and HF
  - Schottky diodes, resistors, and electrochemical cells

- **Approaches**
  - Smart sensor system: sensor arrays, signal processing and conditioning components, power and telemetry
  - “Lick and Stick” for full-field view of environment
  - Nanotechnology and batch microfabrication
  - Small size, low weight, cost, and power consumption

- **Applications**
  - Propulsion system, fuel depot leak detection
  - Low false alarm fire detection.
  - Harsh environment engine emissions monitoring
  - Human health monitoring and potential astronaut health evaluation

- **Sensor to be presented**
  - **CO$_2$ sensors**: Electrochemical cells: amperometric and metal oxide nanomaterial modified, potentiometric sensors and resistors
  - **H$_2$/C$_x$H$_y$ Schottky diode sensors**: Diodes and diodes with contact pads
  - **O$_2$ sensors**: High temp and room temp
  - **NO sensor**: metal oxide resistor based

- **Metal oxide nanomaterials**
Solid Electrolyte Carbon Dioxide Microsensors (NASA GRC)

Side view of microfabricated CO₂ sensor

(Simplified with a pair of two electrodes)

SEM image of a fabricated CO₂ sensor

Testing Results of Solid Electrolyte Carbon Dioxide Sensor

600°C, 1V
Addition of Tin Oxide Nanocrystallines Improves Solid Electrolyte Carbon Dioxide Sensor Performance

Tin oxide nanocrystalline layer added

Sensors without tin oxide sol gel addition

Sensors with tin oxide sol gel addition

Potentiometric CO\textsubscript{2} Microsensors Developed

1\%, 2\%, 3\%, 4\% CO\textsubscript{2} gases in air at 500\degree C, air for baseline

\[ 2\text{Li}^+ + \text{CO}_2 + \frac{1}{2}\text{O}_2 + 2\text{e}^- = \text{Li}_2\text{CO}_3 \] \hspace{1cm} \text{Working}

\[ 2\text{Li}^+ + \text{TiO}_2 + \frac{1}{2}\text{O}_2 + 2\text{e}^- = \text{Li}_2\text{TiO}_3 \] \hspace{1cm} \text{Reference}

< 320 ppm
Development of Diode Sensors with Contact Pads

Fig. 1. A single metal/PdO\textsubscript{x}/SiC based diode for \( \text{H}_2/\text{C}_x\text{H}_y \) detection.

Fig. 2. a) Schottky diode with contact pad fabrication process. b) Image of a Pd/PdO\textsubscript{x}/SiC diode with a Au/Ti contact pad. The dark area surrounding the sensor-pad is SiO\textsubscript{2}.

Fig. 3. Current version of diode with contact pad

Fig 4. a). Sensor with interconnect contact pad responses to 50 ppm, 100 ppm, 150 ppm, and 200 ppm H2 gases; b). Sensor responses to 50 ppm, 25 ppm, and 20 ppm H2 gases, at 300°C, 1V.

Fig. 5. Sensor with interconnect contact pad response to 0.5% H2 at 500°C, 1V.
Developed Room Temperature Potentiometric Oxygen Sensors

*Totally different structure: one of its kind*

- **Working electrode:**
  \[ \text{O}_2 + 4e + 4\text{H}^+ \rightarrow 2\text{H}_2\text{O} \]

- **Reference electrode:**
  \[ 2\text{PdO} + 4e + 4\text{H}^+ \rightarrow 2\text{Pd} + 2\text{H}_2\text{O} \]

**Overall reactions:**
\[ 2\text{Pd} + \text{O}_2 \leftrightarrow 2\text{PdO} \]

- Nafion film with water-retaining components
- Sensor size: 1.88 mm x 2.15 mm
- Reference electrodes: Pd/PdOx on top of Ru electrodes
- Electrode not used in current testing

### Graphs

- **Potential vs. Time**
  - **Air:** 21% O\(_2\) in N\(_2\)
  - **N\(_2\) baseline**
- **Air:** 14% O\(_2\) in N\(_2\)
- **N\(_2\) baseline**

### Additional Information
- Access to Fuel Tank
- Capillaries
- Working Electrode
- Counter Electrode
- Reference Electrode
- To Air
Development of Nitric Oxide and Oxygen Sensors

Pt interdigitated electrodes fabricated on a 2-inch alumina wafer

Gas testing chamber: Probe contact

Electrode structure and schematic of gas testing setup

ITO or YSZ sensing material
High Temperature YSZ Oxygen Sensor Testing Results

(Linear fitting from 0.5% to 16%)
Sputtered ITO Microsensor Response to Nitric Oxide Gas

* Low concentration (ppb to low ppm): adsorption

* High concentration (ppm): adsorption and NO oxidation reaction:

$$ \text{O}_2, \text{NO} \text{ from air grab electrons from ITO surface, deplete ITO surface} $$

\[ \text{ITO film} \]
Metal Oxide Nanomaterials for Reducing Gas Sensing

Increased nano grain boundary contact

SnOx nanocristallines by sol gel process

Polycrystal SnOx nanofibers by electrospun process

SnO2-x

Single crystal nanorods by CVD

Left: Palladium Doped SnOx Nanofibers Detect Hydrogen and Hydrocarbons
Summary

• A variety of chemical microsensors development for aerospace applications

• Different sensor structures and sensing mechanisms were used in the sensor designs

• Carbon dioxide sensors, oxygen sensors, Schottky diode sensors, nitric oxide sensors, and nanomaterials discussed

• Small size, batch fabrication, low cost and power consumption, and harsh environment applications

• Applications: fire detection, engine emission and health monitoring, and environmental monitoring. In ambient and harsh environments
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