Solid Electrolyte Chemical Sensors for Aerospace Applications

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Outline

• Background of Chemical Sensors at NASA GRC

• Solid Electrolyte Chemical Microsensors
  - Oxygen sensors
  - Carbon dioxide sensors

• Summary
Background of Chemical Sensors at NASA GRC

• **Sensors and platforms**
  \[ \text{H}_2, \text{CH}_4, \text{C}_2\text{H}_4, \text{C}_3\text{H}_6, \text{CO}_2, \text{CO}, \text{NOx}, \text{and N}_2\text{H}_4 \]
  Schottky diodes, resistors, and electrochemical cells

• **Approaches**
  Microfabrication, small size, low weight, cost, and power consumption. Batch fabrication, sensor arrays, smart sensor system and use as “Lick and Stick”

• **Applications**
  Engine health and emissions monitoring, fuel leak detection, low false alarm fire detection, and environmental monitoring
Partial Image of a fabricated oxygen microsensor. One material system: Yttria stabilized zirconia (YSZ)

AutoCAD drawing of an interdigitated electrode structure and two contacts

Oxygen Microsensor Structure
Oxygen Microsensor Testing Results

600°C, 1V

Current (A)

Time (min)
Oxygen Microsensor Repeatability Testing

12% in air

600°C, 1V
Oxygen Microsensor Current Vs. Log of Oxygen Concentration
(Linear fitting from 0.5% to 16%)
Oxygen Microsensor Testing Results
Oxygen Microsensor Current Vs. Log of Oxygen Concentrations
(Linear fitting from 0.025% to 0.7%)
Amperometric O$_2$ Microsensor Sensing Mechanism
(Interdigitated electrodes simplified showing one pair of electrodes)

\[ 2O^{2-} - 4e^- \rightarrow 2O_2 \]

\[ 4e^- + O_2 \rightarrow 2O^{2-} \]
Solid Electrolyte Carbon Dioxide Microsensors

Pt interdigitated finger electrode on Al₂O₃ substrate

Carbon dioxide microsensor tested at 600°C, 1V

SEM image of a fabricated CO₂ sensor

Side view of microfabricated CO₂ sensor

(Simplified with two electrodes, patent filed)

<table>
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<tr>
<th>Na₂CO₃/BaCO₃</th>
<th>Pt(+)</th>
<th>NASICON</th>
<th>Pt(-)</th>
<th>NASICON</th>
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<tbody>
<tr>
<td>NASICON</td>
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<tr>
<td>Al₂O₃</td>
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Carbon dioxide microsensor tested at 600°C, 1V
Nanocrystalline Tin Oxide Coated to Reduce Solid Electrolyte Carbon Dioxide Sensor Operation Temperature

Side view of microfabricated CO$_2$ sensor

(Simplified with two electrodes, new tech. disclosed, patent filed)

Coated with SnO$_2$ sol gel, heated at 500°C for 2 hr

Side view of microfabricated CO$_2$ sensor
Coated with Nanocrystalline tin oxide
Nanocrystalline Tin Oxide Improves Solid Electrolyte Carbon Dioxide Sensor Performance

*Sensor Responses Significantly Changed with Nanocrystalline Coating*

Sensors without tin oxide sol gel addition

Sensors after tin oxide sol gel addition
Nanocrystalline Tin Oxide Improve Solid Electrolyte Carbon Dioxide Sensor

Solid Electrolyte CO₂ Sensor with Nanocrystalline SnO₂
(Detection temperature greatly reduced from 600°C to 375°C)
Sensing Mechanism of Solid State Electrochemical Sensors for Carbon Dioxide Gases

- Reduction reaction at Pt(-) electrodes
  \[ 2\text{Na}^+ + \text{CO}_2 + \frac{1}{2} \text{O}_2 + 2\text{e}^- \rightarrow \text{Na}_2\text{CO}_3 \]

- N-type metal oxides: supply more electrons or enhance electrons flow

- Results: Detection temperature decreased and power consumption reduced
Summary

• Oxygen and carbon dioxide microsensors developed using same microsensor platform

• Oxygen sensor uses one sensing material system YSZ. By depositing the right thickness, YSZ can be both diffusion barrier and sensing material. Simplest sensor fabrication but wide oxygen detection was achieved: linear current response to the log of oxygen concentration from 0.025% to 16%

• Carbon dioxide sensor using two-material sensing system uniquely fabricated on interdigitated electrode, forming robust structure. Wide carbon dioxide detection achieved. Linear current response to the log of carbon dioxide concentration from 0.02% to 2% in air

• Solid electrolyte CO₂ sensor improved and sensor power consumption decreased through addition of n-type SnO₂ nanomaterial. CO₂ operation temperature decreased from 600°C to 375°C. CO₂ in air from 0.5% to 4% was tested

• Further improvement including expending sensor detection ranges and further reduce power consumption by reducing operation temperature.

• Oxygen and carbon dioxide microsensors can be used for aerospace applications such as fire detection and environmental monitoring.
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