Study on the Performance of Sensitive Part of Bridge Type Ultra-thin Film Hydrogen Sensor

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Introduction of the presenter

Education:
- He received a bachelor's degree from Okayama University in 3.2021
- Currently, he is a master’s program student at Okayama University

Expertise
- Electrical engineering
  - Chemical sensor
  - Semiconductor device

Takahiro Mori
Research background

- A large amount of CO$_2$ emission of fossil fuels is a major problem

- For example, under the Paris Agreement, countries are required to reduce their CO$_2$ emissions

- Therefore, problem of CO$_2$ emission leads us to develop new clean energies, including solar, wind, and hydrogen energy
Demand for hydrogen is increasing

Problems with Hydrogen energy

- Hydrogen energy has two problems
  - Easy to leak from container
  - Wide burning range (4% ~ 75%)

Hydrogen sensor

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Conventional hydrogen sensor

- There are many hydrogen gas sensors.
  - Semiconductor gas sensor, Catalytic combustion type gas sensor, Thermal conductivity gas sensor

- These sensors can only be used under high temperatures
  - Therefore, they require heaters and power supply for heaters

The Pt ultra-thin film hydrogen sensor can operate without heaters
Pt ultra-thin-film hydrogen sensor

Using the catalytic action of platinum with hydrogen

More electrons in the Pt by a catalytic action, the electrical resistance is changed
The problem of the Pt ultra-thin-film hydrogen sensor

The electrical resistance of the Pt film changes by the temperature, so the output signal of the conventional Pt hydrogen sensors is affected by operating temperature.
The output voltage by the Wheatstone bridge circuits of the Pt ultra-thin-film hydrogen sensor

\[ V = V_b - V_a \]

\[ = \frac{-r}{200-r} E \]

\[ V_b = \frac{R'}{R + R'} E \]

\[ V_a = \frac{R}{R + R'} E \]

\[ R' = \frac{100 - r}{100} R \]

The effect of environment can be reduced

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Structure of hydrogen sensor

The cross section of the sensor

- Pt (10 nm)
- TiN (20 nm)

The surface of the sensor

- Coated with alumina

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Experimental Equipment

Air (80%-N2 and 20%-O2)
H₂ 1% (Air balance)
H₂ 0.1% (Air balance)
H₂ 100ppm (Air balance)
H₂ 10ppm (Air balance)

H₂ 1% (N₂ balance)
CH₄ 1% (N₂ balance)
C₂H₆ 1% (N₂ balance)
CO₂ 1% (N₂ balance)

Gas switcher

Chambar

Gas

Hydrogen sensor

A/D converter (measuring voltage)

Voltage source

sensor signal

PC

control

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Hydrogen concentration measurement

The hydrogen sensor was exposed to hydrogen gas for 5 minutes each concentration.

In this experimental equipment, the sensor can detect hydrogen gas with a concentration of above 100ppm.
Temperature dependence

The hydrogen sensor was exposed to Air for 5 minutes under the temperature between 30 and 90 °C

The voltage response of 1%-hydrogen gas exposure was **14.9 mV**

The range of dispersion was **0.31 mV**

0.31 mV was less than 2% of the voltage response of 1%-hydrogen gas exposure.

The voltage drift due to the temperature change could be reduced by forming the Wheatstone bridge circuits.
Surface area dependence of the sensitives

Each sensor was exposed to 1%-hydrogen gas for 5 minutes

As surface area increases, sensitivity increases linearly

<table>
<thead>
<tr>
<th>Sensing area of hydrogen sensor</th>
<th>Width (µm)</th>
<th>Length (µm)</th>
<th>Area (mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>270</td>
<td>5.40×10⁻³</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>440</td>
<td>8.80×10⁻³</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>2650</td>
<td>0.265</td>
<td></td>
</tr>
<tr>
<td>150</td>
<td>2700</td>
<td>0.405</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>4400</td>
<td>0.440</td>
<td></td>
</tr>
</tbody>
</table>

2.3 mV/mm²
Gas selectivity

The hydrogen sensor was exposed to CH₄, C₂H₆, CO₂, H₂ for 5 minutes

- 1% CH₄, C₂H₆ and CO₂ gas was evaluated to be less than 0.1 mV
- 1% H₂ was evaluated to 26 mV

The gas selectivity to hydrogen gas was above 260% to 1% CH₄, C₂H₆, and CO₂ gas.
Humidity dependence

The hydrogen sensor was exposed to 1% hydrogen gas for 5 minutes under the humidity between 20 and 70%.

Sensitivity decreased due to humidity.

The sensor can operate even under the high-humidity condition of 70%.
Conclusion

- We developed a highly sensitive and selective Pt ultra-thin-film hydrogen sensor
- The effect of temperature for Pt can be reduced by forming Wheatstone bridge circuits
- The sensor can be more sensitive by surface area increasing
- Under 70% humidity, the hydrogen sensor can detect hydrogen gas