
O₂-Measurement Principle

AN002e-0 (12/2025)

Scope

Outlines the measurement principle and basic characteristics of an amperometric ZrO₂ based sensor.

1 Basic Principle

The oxygen ion transport properties of Zirconia were investigated by Kiukkola and Wagner in 1957. They found, that partially stabilised Zirconia was an excellent candidate for oxygen sensing applications, as above 300°C the material is a selective oxygen ion conductor. Modern zirconia-based sensors use Yttria-stabilized zirconia (YSZ), reaching an optimal conductivity at around 600°C.

What do we need in order to generate an oxygen ion current?

- Two surface electrodes
- A stable temperature of ~600°C
 - For our sensors we have chosen a working temperature of ~580°C
- A stable electrode bias voltage (0.6-1.6V)

Oxygen is then ionized at the top electrode and as the electro-motive force between the two surface electrodes induce an oxygen ion current within the ZrO₂ material and is limited by ion mobility of the YSZ solid electrolyte in ambient air (not the oxygen content).

2 The Current Limited Amperometric Design

Due to its high oxygen ion conductivity, the oxygen ion current of bare ZrO₂ shows no correlation to the oxygen concentration of the medium in most applications as the ZrO₂ is saturated.

Thus, one needs to limit the oxygen flow with other means – this is commonly done by either introducing a porous barrier or a barrier with a small diffusion opening. This barrier must be separated from the solid Zirconia electrolyte and the electrodes, forming a small chamber that is depleted of oxygen.

We have designed our sensors around the diffusion opening approach as it offers better response time and shows an improved response to pressure changes. By altering the size of the diffusion opening one can adjust the measurement range.

2.1 Sensor operation and the O₂ Measurement

The sensors (1) heating element brings it to operating temperature. Then, the electrode bias (between (3) and (5)) is applied, which transports the oxygen within the chamber between the plate of the (2) diffusive barrier and the (4) zirconia electrode plate to the anode and expels it at the back of the sensor. We can then assume, that this internal volume is free of oxygen and the sensor current is only influenced by the influx of oxygen via the diffusion opening.

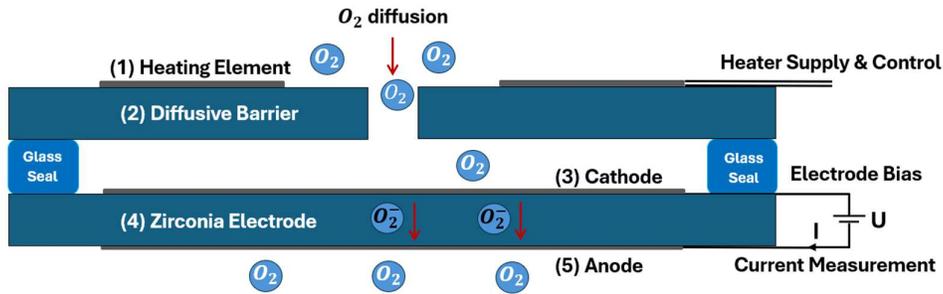


Figure 1: Schematic cross section view of the current limiting zirconia sensor

This can be expressed via the following formula, that is valid for all sensor types and for all calibration gas concentrations:

$$I_s([O_2]) = -k \cdot \ln\left(1 - \frac{[O_2]}{100}\right)$$

- $I_s([O_2])$ Sensor current in the measuring medium
- $[O_2]$ Oxygen concentration in the measuring medium in %
- k Sensor-specific constant

2.2 Advantages and Limitations of the Zirconia Oxygen Sensor in Real World Applications

2.2.1 Advantages

- ZrO_2 is chemically very stable
- Physically robust
- Small sensor chip size
- Very selective – only conducts oxygen ions
- Very sensitive
- Very low drift – no recalibration needed
- Good signal/noise ratio (practically no electron conductivity)
- Can be operated in overrange conditions
- Influence of pressure changes

2.2.2 Limitations

- High temperature of operation - May exceed the ignition point requirements in some applications
 - Not suitable for many EX-applications
- Combustible compounds (e.g.: silanes) in the medium may contaminate the sensor
- Condensing moisture can damage the sensor during heat-up
- Compounds may bind (e.g.: CO) oxygen, altering the concentration
- At low O₂-levels compounds may release oxygen (e.g.: H₂O), this can be avoided by observing the lower detection limit of each sensor range or by reducing the bias voltage.

2.3 Typical Sensor Values and Parameters

The exact values will depend on the housing, range and application.

Sensor current	1µA ... 420µA
Recommended bias voltage	0.6V ... 1.6V
Heater resistance	3.25 Ohm (at 25°C)
Heater supply voltage	3.6V ... 4.1V
Heater current	350mA ... 450mA
Heater track material	Pt
Operating Temperature	560°C ... 600°C

