

CO/HC Gas Sensor Using a Powder Aerosol Deposited Thermoelectric Material

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Summary:

This study presents a CO/HC gas sensor designed for operation at high temperatures in harsh environments, such as the flue gas of biomass combustion systems. The sensor principle is based on an indirect thermoelectric effect caused by exothermic reactions, which enables the detection of unburned flue gas components. A special feature of the sensor is its manufacturing process, whereby structured lines of a thermoelectric material are fabricated using the powder aerosol deposition method. As a result, significantly enhanced sensor sensitivity was achieved compared to the conventional sensor design.

Keywords:

Emission Monitoring, High Temperature Gas Sensor, Biomass Combustion, Powder Aerosol Deposition (PAD), Thermoelectrics

Motivation

The increasing use of biogenic residual fuels such as wood for energy production requires reliable emission monitoring, particularly of carbon monoxide (CO) and hydrocarbons (HC) as indicators of incomplete combustion [1]. Conventional gas analysis systems are often expensive, maintenance-intensive, and limited in their suitability for continuous in-situ operation. Thermoelectric gas sensors offer a robust alternative well suited for harsh environments [2]. This work presents a CO/HC sensor that relies on an indirect thermoelectric sensing effect resulting from exothermic reactions at a catalytic active film. The manufacturing process of the thermoelectric components involves the use of the powder aerosol deposition method (PAD). This novel approach includes the production of structured, optimized functional films, which contribute to reliable emission monitoring during biomass combustion.

Sensor Setup and Fabrication

The sensor element is based on a ceramic substrate containing a screen-printed platinum heater structure on the reverse side. It is realized in a four-wire configuration and insulated by an additional cover layer [2]. On the front side, a thermopile structure is integrated to detect temperature differences across the sensor. This temperature difference is generated by a one-sided applied catalytically active film that exothermically converts unburned hydrocarbons

(HC) and carbon monoxide (CO) [3]. Thus, the sensor provides a voltage signal that depends on the concentration of unburned flue gas components. A schematic image is shown in Fig. 1a) and a real sensor without the catalytic active film is shown in Fig. 1c).

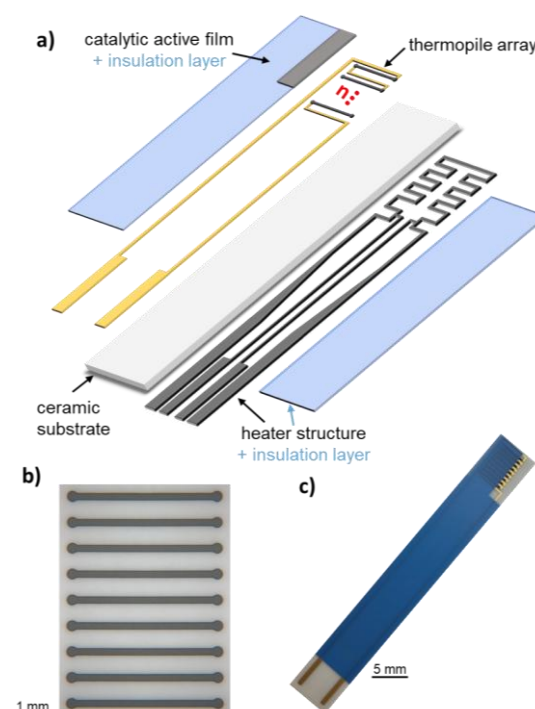


Fig. 1. Setup of the CO/HC sensor. a) Schematic picture. b) CCO thermocouple junctions with a line width of 200 μm , fabricated using the PAD method, c) real sensor without catalytic active film

In contrast to previous sensor designs, no gold–platinum combination is used for the thermopile structure. Instead, platinum is replaced by the thermoelectric material calcium cobalt oxide ($\text{Ca}_3\text{Co}_4\text{O}_9$, CCO), which offers a significantly higher relative Seebeck coefficient ($|S_{\text{Au/CCO}}(600^\circ\text{C})| \approx 160 \mu\text{V/K}$ in comparison to $S_{\text{Au/Pt}}(600^\circ\text{C}) \approx 19 \mu\text{V/K}$) [4,5]. This thermoelectric material is deposited using the powder aerosol deposition method (PAD), in which the CCO powder is accelerated into a vacuum chamber and directly deposited onto the substrate at room temperature. This process enabled the fabrication of structured lines with widths of approximately $200 \mu\text{m}$ (see Fig 1b)).

Results and Discussion

The sensor characterization was carried out under laboratory conditions using sensors with nine thermocouple pairs. To provide a basis for comparison, sensors with Au/CCO thermopiles were evaluated along with reference sensors that had conventional Au/Pt thermopiles (according to [3]).

Fig. 2 shows the temporal response of the sensor signals measured at a sensor temperature of 600°C . In this measurement, different concentrations of CO and C_3H_6 were dosed and the voltage change ΔU was evaluated.

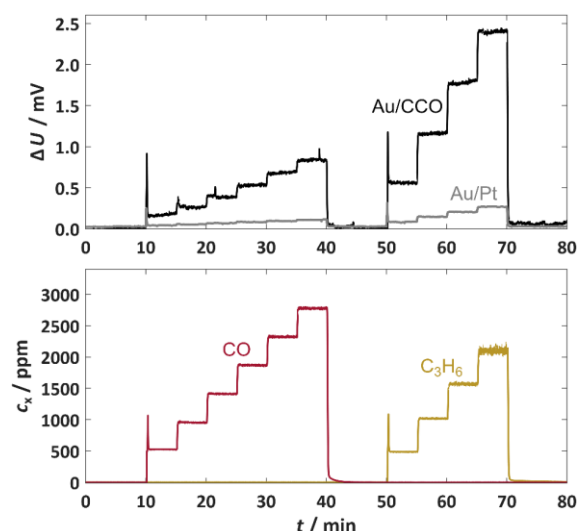


Fig. 2. Time course of sensor responses at varying CO and C_3H_6 concentrations at a sensor temperature of 600°C , base gas: 15 vol% O_2 , 5 vol% H_2O , 3 vol% CO_2 in N_2

The measurement shows that the voltage change obtained with the Au/CCO sensor is significantly higher than that of the Au/Pt sensor. For CO exposure, a sensitivity of $305 \mu\text{V}$ per 1000 ppm was determined, while propene generated a response of $1167 \mu\text{V}$ per 1000 ppm, corresponding to approximately a ninefold increase compared to the Au/Pt sensor ($32 \mu\text{V}$ per

1000 ppm for CO and $121 \mu\text{V}$ per 1000 ppm for C_3H_6). Thus, the signal increase can be attributed to the Seebeck coefficient ratio of the thermopile combinations, assuming identical temperature differences at the sensors.

Further measurements demonstrated that cross-sensitivities to water vapor and oxygen were extremely low. Due to the nearly temperature-independent Seebeck coefficient of CCO around 600°C , fluctuations in sensor temperature have only a minor impact on the sensor signal. This can contribute to a stable and robust sensor response under varying operating conditions. Further investigations will therefore focus on validating the sensor performance under realistic conditions by conducting measurements in the real flue gas of a wood-fired furnace.

References

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