

# Ammonia flue gas sensors for SCR applications: A comparison between zeolite-based capacitive sensors and mixed-potential sensors utilizing vanadia-based electrodes

Ralf Moos<sup>1,2</sup>, Thomas Wöhrl<sup>1,2</sup>, Nils Donker<sup>1</sup>, Daniela Schönauer-Kamin<sup>1</sup>, Gunter Hagen<sup>1,2</sup>

<sup>1</sup> Department of Functional Materials, University of Bayreuth, 95447 Bayreuth, Germany,

<sup>2</sup> Center of Energy Technology (ZET), University of Bayreuth, Germany  
Functional.Materials@Uni-Bayreuth.de

## Summary:

Two different, planar, and very selective ammonia sensor types are compared in this study with regard to their applicability in flue gas from biomass combustion processes: a YSZ-based mixed potential sensor and a zeolite-based capacitive sensor. Both are operated at several hundred °C. The zeolite sensor shows a small cross-sensitivity to water vapor, whereas the signal of the mixed-potential sensor depends on O<sub>2</sub>, especially at lower oxygen concentrations. In both cases the signal can be corrected by a lambda-probe. Both sensors behave well in real exhausts, both in flue gas and in real engine exhausts.

**Keywords:** Sensors for selective catalytic reduction (SCR), biomass combustion, zeolite-based sensors, mixed-potential sensors, high-temperature sensors

## Background, Motivation and Objective

Biogenic materials are often used for CO<sub>2</sub>-neutral energy production. For the combustion of biomass, limits for nitrogen oxide emissions (NO<sub>x</sub>) have to be met as well. Therefore, SCR (Selective Catalytic Reduction) systems are required. Here, ammonia (NH<sub>3</sub>) or NH<sub>3</sub>-forming substances (like liquid urea-water solutions) are added to the flue gas. NH<sub>3</sub> serves as a reducing agent for NO<sub>x</sub>. In order to control SCR-systems and/or to monitor their functionality, NH<sub>3</sub> sensors are required. Besides, NH<sub>3</sub> is seen as a CO<sub>2</sub>-free energy carrier that can be shipped worldwide and that can even be burned directly in NH<sub>3</sub> combustion engines. Therefore, there is a need for selective and reliable NH<sub>3</sub> sensors, too.

This contribution compares two recently in our group developed sensor types for flue gas application: a capacitive zeolite-based and a YSZ-based NH<sub>3</sub> sensor.

## Principles and Technology

The basic technological setup of both sensor types is similar. They are made in planar ceramic thick-film technology, which is well-established for years. On the lower side of the alumina substrate, there is a covered heater structure that also serves as a temperature sensor (Fig. 1a). On the upper side of the sensor tip, either planar interdigital electrodes covered by a zeolite functional film (Fig. 1c) or a YSZ film and two

gold electrodes are applied. As a process simplification, the dense YSZ film was made by the recently developed powder aerosol deposition method (PAD or ADM) [1,2]. One electrode is covered with an SCR-active porous layer (Fig. 1b) that is responsible for the difference in the potential ( $U$ ) between both electrodes in the presence of NH<sub>3</sub>. It consisted of a commercial formulation based on vanadia, tungsten oxide, and titania (abbr. VWT) supplied by Johnson Matthey.

The sensor readout for the zeolite sensor is either impedimetric, or, if one stays at a defined frequency, here 700 kHz, the capacitance change can be used as the signal. As a remarkable feature, the interdigital electrode (IDE) structure was patterned to a line width and spacing of 20 μm [3,4]. The gas sensitive layer was a commercial H-ZSM5 zeolite with a module of 27 from ALSI Penta Zeolite GmbH.

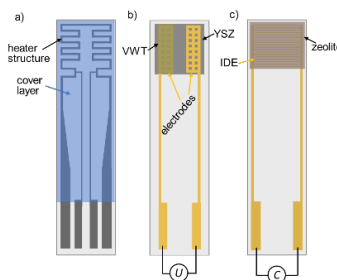


Fig. 1. Setup of the two sensors types.

### YSZ-based NH<sub>3</sub> Mixed-Potential Sensor

The sensors were exposed to a synthetic exhaust containing water vapor, O<sub>2</sub>, and N<sub>2</sub>, as well as NH<sub>3</sub>, NO and/or NO<sub>2</sub> as indicated. First of all, an optimum sensor temperature was looked for and 550 °C turned out to be a good compromise between sensitivity and noise. CO<sub>2</sub>, and C<sub>3</sub>H<sub>8</sub> were also added to the base gas and the sensors did not show any response to them.

A variation in the water vapor concentration did not affect the sensor signal  $U$ , too. At 550°C, the effect of varying O<sub>2</sub> concentrations, as it occurs in flue gas and the effect of NO, and NO<sub>2</sub> were studied. The results are shown in Fig. 2. Obviously, only at low O<sub>2</sub> concentrations in the exhaust, there is a dependency on NO<sub>x</sub>, with NO and NO<sub>2</sub> showing opposite signals.

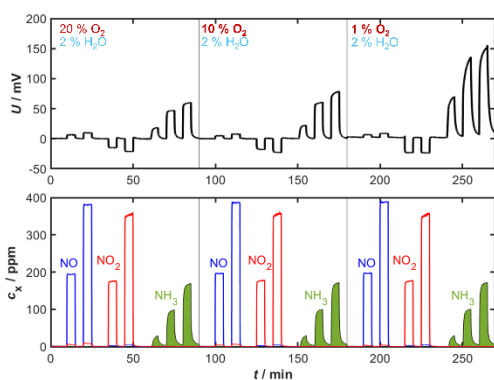


Fig. 2. Response of the mixed-potential NH<sub>3</sub> sensor.

### Capacitive Zeolite-based NH<sub>3</sub> Sensor

Similar tests have been performed with the capacitive zeolite-based sensors. Here, 400 °C turned out to be the optimum temperature. The base gas consisted of O<sub>2</sub>, CO<sub>2</sub>, water vapor, and N<sub>2</sub> (as a balance). NO, NO<sub>2</sub> and NH<sub>3</sub> were added as indicated. The results are shown in Fig. 3. Obviously, O<sub>2</sub> variations and additional tests with C<sub>3</sub>H<sub>8</sub>, CO, or H<sub>2</sub> do not affect the sensor response. However, the influence of water vapor on the sensor signal becomes noticeable.

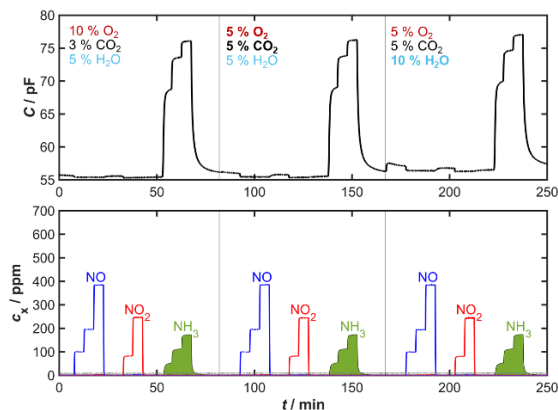


Fig. 3. Response of the zeolite-based NH<sub>3</sub> sensor.

### Results and Discussion

Since the materials that are used for the sensor are well-known for harsh exhaust applications, long-term stability can be expected and has also been observed. Both sensors are very selective towards other components that may be present in flue gas exhausts. The mixed-potential sensor is operated at around 550°C. As a result, it requires slightly higher power than the zeolite sensor (400°C). However, it is better protected against soot deposits, as soot already burns off at this temperature. The zeolite sensor shows a small cross-sensitivity to water vapor (due to the sensor principle). This can be eliminated using an additional lambda probe or a humidity sensor. The mixed-potential sensor, however, is not sensitive to water vapor, but (also owing to the mixed-potential sensing mechanism) its signal depends on O<sub>2</sub>, especially at lower oxygen concentrations. The signal can be corrected by a lambda-probe, too.

When NH<sub>3</sub> and NO<sub>x</sub> are simultaneously present in the flue gas, one has to consider that both gas sensitive materials, zeolite H-ZSM5 and VWT catalyze the SCR reaction. Therefore, there is some cross-sensitivity towards NO<sub>x</sub> if NH<sub>3</sub> is present, which has been very recently investigated in detail [4]. Especially NO<sub>2</sub> that is more SCR-active than NO is responsible for this interfering effect (so-called fast SCR reaction).

Further tests showed that both sensors behave well in real exhausts, both in flue gas and in real engine exhausts. These data will be presented in the conference as well.

### References

- [1] M. Schubert, et al., Powder aerosol deposition method — novel applications in the field of sensing and energy technology, *Functional Materials Letters*, 12, 1930005 (2019); doi: 10.1142/S1793604719300056
- [2] N. Donker, D. Schönauer-Kamin, R. Moos, Mixed-Potential Ammonia Sensor Based on a Dense Yttria-Stabilized Zirconia Film Manufactured at Room Temperature by Powder Aerosol Deposition, *Sensors*, 24, 811 (2024), doi: 10.3390/s24030811
- [3] T. Wöhr, J. Kita, R. Moos, G. Hagen, Capacitive, Highly Selective Zeolite-Based Ammonia Sensor for Flue Gas Applications, *Chemosensors*, 11, 413 (2023), doi: 10.3390/chemosensors11070413
- [4] T. Wöhr, R. Moos, G. Hagen, Analyzing the cross-sensitivities of a zeolite-based ammonia sensor for SCR systems for application in the flue gas of biogenic waste combustion, *Sensors and Actuators B: Chemical*, 436, 137727 (2025); doi: 10.1016/j.snb.2025.137727.