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Impedimetric NO_x sensor for exhaust applications with internal lambda correction

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Abstract

Due to current developments in the automotive industry, more attention has to be paid to exhaust aftertreatment. Robust and cost-effective sensors for monitoring and controlling the exhaust aftertreatment systems are required, especially for NO_x detection. We suggest an impedimetric NO_x sensor which is fully manufactured in planar thick film technology. The impedance of a functional layer ($KMnO_4$ supported on Al_2O_3) reacts selectively to the NO_x concentration in the exhaust. However, this mechanism depends on the air-fuel-ratio (Lambda). For this reason, a resistive O_2-sensitive functional layer (BFT) is additionally applied to the sensor element. Using this signal of the O_2-sensitive functional layer, the existing lambda can be determined and thus the lambda dependency of the NO_x-sensitive functional layer can be corrected.

Keywords: impedimetric gas sensor, oxygen sensor, exhaust gas sensor, NO_x sensor, O_2 sensor

Introduction

In the course of the current developments in the automotive industry, it is necessary to pay special attention to efficient exhaust aftertreatment. For NO_x abatement of the exhaust gases, there are different possibilities (storage catalytic converters or SCR-concepts). All of these aftertreatment systems need to measure the NO_x concentration in the exhaust gas as a variable. Available NO_x sensors are based on electrochemical ZrO_2 cells. Design and production of such sensors are complex and cost-intensive. In this study, an impedimetric sensor concept is proposed. It can be fully realized in planar thick film technology. [1-2]. The sensitivity of the measured signal depends not only on the nitrogen oxide concentration but also on the lambda value of the exhaust gas. For this reason, the sensor element is extended by an additional O_2 sensor layer. Thus, in addition to the NO_x signal, information about the oxygen content of the exhaust gas can be determined. Now, a correction of the impedimetric signal of the NO_x measurement is possible [3].

Description of the sensor setup

Sensor elements are completely built in planar thick film technology on Al_2O_3 substrates. On the front side there is a NO_x-sensitive functional layer of potassium permanganate ($KMnO_4$) supported on Al_2O_3 (Figure 1, brown). The contacting of the functional layer is realized by planar interdigital electrodes, which allows an impedance-based measurement. In addition to the NO_x-sensitive functional layer, an O_2-sensitive functional layer of barium iron tantalate (BFT) is screen-printed on the front side of the sensor (Figure 1, black). This functional layer is contacted by two electrodes and can be measured resistively. A meander-shaped heater structure is applied on the reverse side. It heats up the sensor to the required operating temperature. For more details on the sensor design see Ref. [3].

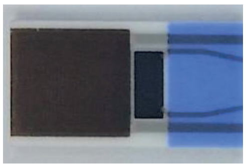

Figure. 1: Top view of the functional part of the sensing element (brown: NO_x-sensitive functional layer, black: O_2-sensitive functional layer).

Experimental

The sensor is installed in a lab test bench (atmospheres by gas dosing from cylinders) and heated to an operating temperature of 650 °C via the heater structure on the reverse side. The base gas (total flow 6000 ml/min) contains 10 % O_2, 3 % CO_2 and 2 % H_2O with N_2 as carrier gas (yellow background in Figure 2). By mass-flow-controllers (MFCs), first NO

(100 ppm, 300 ppm, 600 ppm) and then NO_2 (100 ppm, 300 ppm) is added to the base gas. After that, the base gas is changed to N_2 with 2 % O_2, 7 % CO_2 and 2 % H_2O (blue background in Figure 2). The stepwise dosing of NO and NO_2 is repeated here.

For the NO_x-sensitive functional layer, the bulk resistance of the functional layer acts as the sensor signal. It is calculated from the impedimetric signal as follows, assuming a semi-circle behaviour in the complex plane (Equation 1):

$$R = |\underline{Z}| / \cos(\varphi) \tag{1}$$

Both sensor signals (NO_x and O_2) were evaluated as relative change based on the resistance R_0 before test gas dosing to compare the results.

Results and Discussion

Figure 2 shows the sensor signals of both functional layers for NO_x variation in two gas atmospheres. The black curve (Figure 2) shows the signal of the NO_x-sensitive functional layer. The signal reacts clearly to the addition of NO and NO_2 in both gas atmospheres. However, the sensitivity of the NO_x-sensitive functional layer decreases with an decreased lambda value. The O_2-sensitive functional layer shows a dependency on lambda and thus on the present O_2 content. Additionally, a slight cross-sensitivity to NO_2 can be recognized. This could be caused by a too low temperature at the functional layer [4]. However, the signal of the O_2-sensitive functional layer can now be used to correct the lambda dependency of the NO_x-sensitive functional layer.

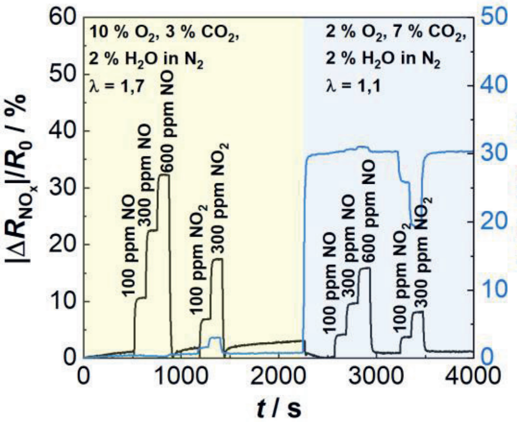

Figure 2: Sensor signal of both functional layers at two different gas atmospheres (base gas: 10 % O_2, 3 % CO_2, 2 % H_2O in N_2; atmosphere 2: 2 % O_2, 7 % CO_2, 2 % H_2O in N_2) with a variation of NO (100 ppm, 300 ppm, 600 ppm) and NO_2 (100 ppm, 300 ppm).

For this purpose, NO_x-dependent characteristic curves at different lambda atmospheres were measured and a lambda-dependent characteristic curve of the O_2-sensitive functional layer was recorded in further experiments. By using these characteristic curves, the signal of the NO_x-sensitive functional layer can be corrected and converted into a NO_x.concentration. The result of this correction is shown in figure 3.

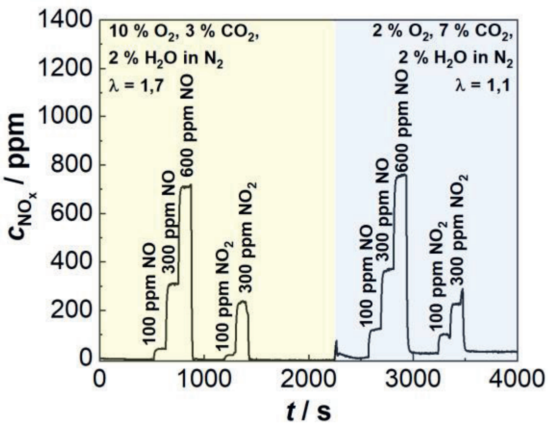

Figure 3: Result of the corrected sensor signal of the NO_x-sensitive functional layer.

Conclusion

The described sensor element can be used as an alternative NO_x sensor in exhaust applications. However, since the NO_x-sensitive signal depends on the predominant lambda, an additional O_2-sensitive functional layer is integrated. With this setup, it is possible to correct the lambda dependence of the NO_x-sensitive sensor signal and to convert the signal into a NO_x concentration.

References

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