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# Study of YSZ electrolyte inks for preparation of screen-printed mixed-potential sensors for selective detection of NO<sub>x</sub> and NH<sub>3</sub>

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**Abstract:** Among all NO<sub>x</sub> reduction approaches, selective catalyst reduction (SCR) system is one the most reliable ways to control NO<sub>x</sub> emissions from diesel engine vehicles and trucks. In order to optimize the conversion rates of NO<sub>x</sub> and to prevent inducing excessive NH<sub>3</sub> to the air, an NH<sub>3</sub> and NO<sub>x</sub> sensor is required [1]. In this study, three different types of YSZ ink have been examined to identify the most effective electrolyte for NO<sub>x</sub> and NH<sub>3</sub> sensing. The results have shown that a home-made ink with YSZ powder shows the best sensitivity towards ammonia without polarization and the highest NO<sub>2</sub>/NO signal ratio with polarization current of 25 nA.

**Keywords:** Mixed-potential sensor; NO<sub>x</sub>; Yttria Stabilized Zirconia; NH<sub>3</sub>; Electrolyte

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## 1. Introduction

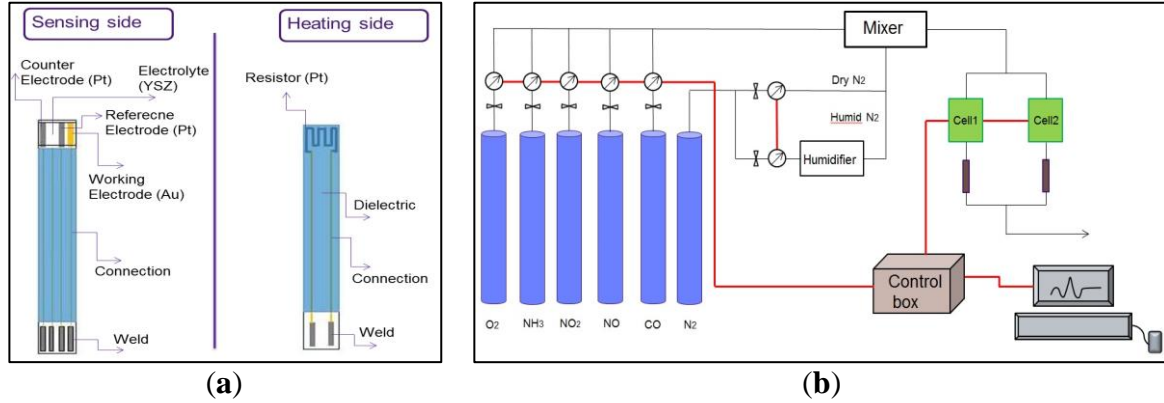
Nowadays, one of the biggest concerns of public and politicians, is air pollution with a major focus on poor air quality and its effects on the life in urban areas [2]. In order to decrease this concern, a lot of NO<sub>x</sub> (which mostly contribute to NO<sub>2</sub> concentrations) reduction approaches have been developed recently which among them Selective Catalytic Reduction system (SCR) is one of the most cost-effective and fuel-efficient diesel engine NO<sub>x</sub> emissions control technologies. Since the DeNO<sub>x</sub> selective catalytic reduction system uses ammonia as the reducing agent, the concern of NH<sub>3</sub> being injected into the atmosphere has been rose up in heavy duty diesel vehicles [3]. J.P Viricelle et al. in 2015 [4] have developed mixed-potential selective NO<sub>2</sub> sensors. Based on this study, we aim to develop sensors for selective detection of both NO<sub>x</sub> and NH<sub>3</sub> for automotive exhaust.

## 2. Materials and Methods

In this study, different sensors are fabricated by using commercial and home-made ink by the method of screen-printing. The used inks are consisting of a powder of inorganic material (active element), a binder and an organic solvent. As solid electrolyte we used a commercial YSZ ink (named ink A) sintered at 1380 °C or 1480 °C and also home-made ink using YSZ powder (named ink B) sintered at 1380 °C. For the electrodes, we used gold (ESL 8880-H) and platinum (ESL 5545) commercial inks and for the connectors we used the same ink as gold electrode. The welding areas were made from a palladium and silver commercial ink (ESL 9635BT). A schematic figure of fabricated sensors is shown in figure 1(a).

In order to evaluate the performance of the fabricated planar sensors, the response to different pollutant gases such as CO, NH<sub>3</sub>, NO<sub>2</sub> and NO in respective amounts of 100, 20, 100 and 100

ppm are studied at 450 °C and in a base gas composed of 12% O<sub>2</sub> and 1.5 % H<sub>2</sub>O, balanced with N<sub>2</sub>. The test bench that we use in this study is presented in figure 1(b). The gases are controlled by mass flow regulators and arrive first in a mixing chamber before being sent to two cells which each contains one sensor. A vaporizer allows performing the tests in humid atmosphere.



**Figure 1.** A schematic figure of: (a) solid-state fabricated gas sensors; (b) experimental set-up at EMSE.

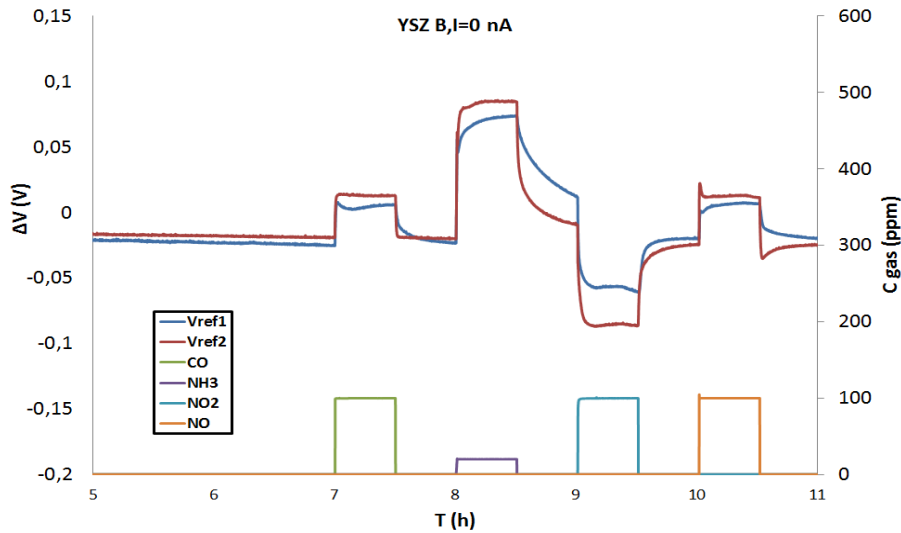
In addition, by applying a constant polarization current of 25 nA between working electrode (Au) and counter electrode (Pt), the sensor responses ( $\Delta V$ ) are measured between working electrode and reference electrode (Pt) according to equation 1.

$$\Delta V = V_{RE}(Pt) - V_{WE}(Au), \quad (1)$$

$V_{RE}$ : Potential of the reference electrode;  $V_{WE}$ : Potential of the working electrode

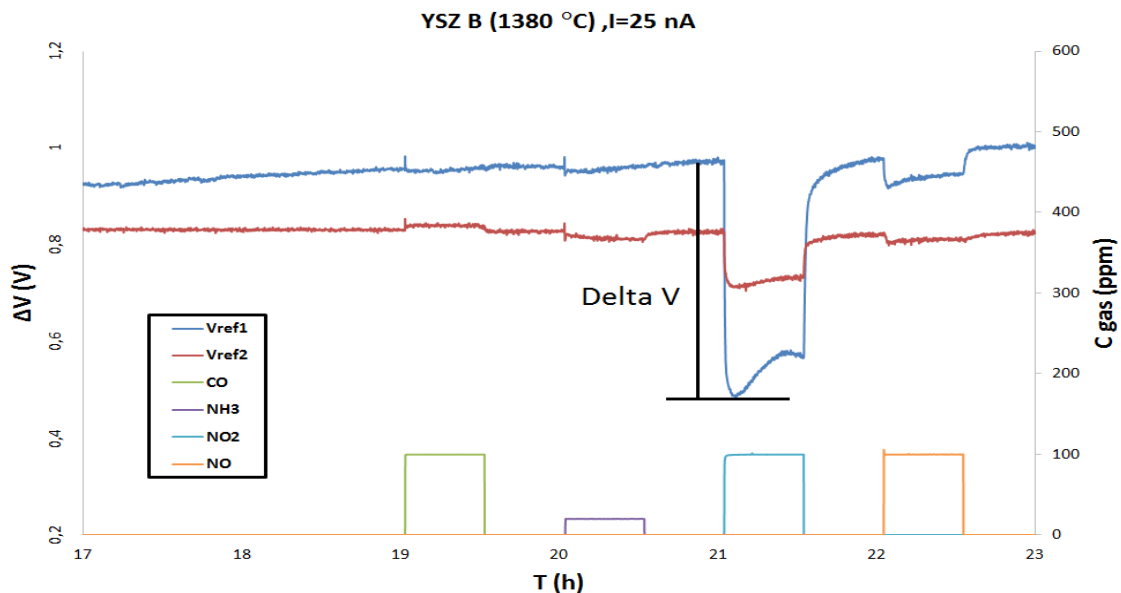
### 3. Results and discussions

In order to take into account irreproducibility of the sensors due to fabrication process, all tests are repeated with two sensors (1 and 2). The OCV values (Open Circuit Voltage, no polarization) were measured in the base gas for 30 minutes upon  $i_{pol} = 0$ . In figure 2, we observe the expected response in the opposite direction for reducing gas such as CO, NH<sub>3</sub> and NO (positive comparing with the baseline) and the oxidizing gas NO<sub>2</sub> (negative to baseline).



**Figure 2.** Responses ( $\Delta V$ ) of the three-electrodes sensors with YSZ B at 450 °C during pulses of CO (100 ppm), NH<sub>3</sub> (20 ppm), NO<sub>2</sub> (100 ppm) and NO (100 ppm) in base gas without polarization current.

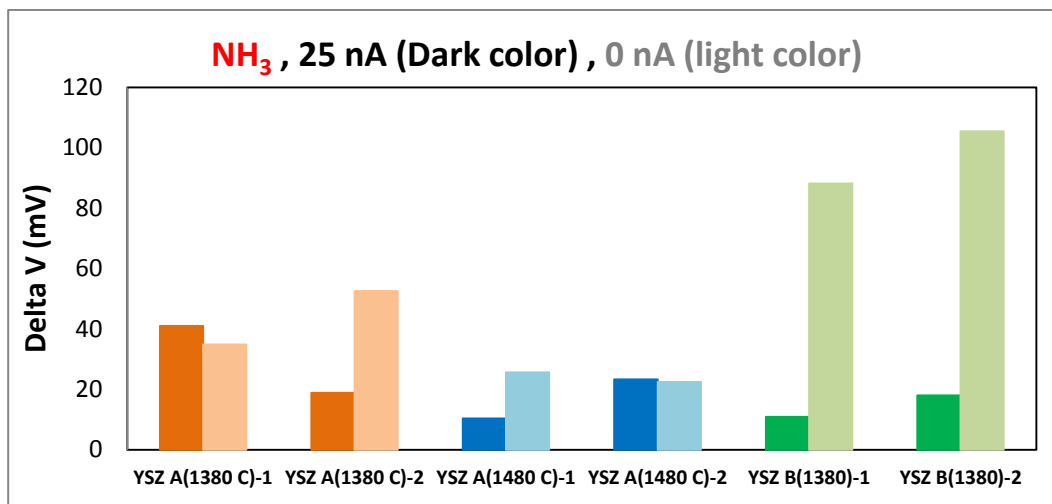
Since NO<sub>2</sub> is an oxidizing gas, the galvanostatic mode can only produce the electro-chemical reduction of NO<sub>2</sub> at working electrode. Figure 3 shows the variations of the potential ( $\Delta V$ ) for sensors with YSZ B at 450°C for different gases by applying a polarization current of 25 nA. In these conditions it can be obviously seen that the responses to other interfering gases such as CO and NH<sub>3</sub> are almost removed while there is relatively a good selectivity towards NO<sub>2</sub>.



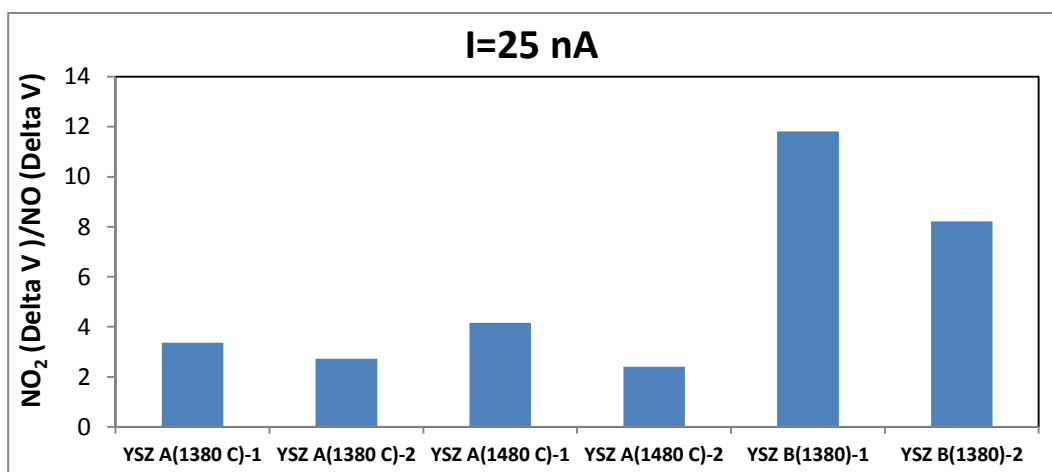
**Figure 3.** Responses ( $\Delta V$ ) of the three-electrodes sensors with YSZ B at 450 °C during pulses of CO (100 ppm), NH<sub>3</sub> (20 ppm), NO<sub>2</sub> (100 ppm) and NO (100 ppm) in base gas with a polarization current of 25 nA.

The responses of different sensors (YSZ A 1380 and 1480 °C, YSZ B 1380 °C) to 20 ppm of ammonia are shown in figure 4. This bar chart clearly illustrates that without polarization the

sensors with YSZ B give the most significant responses toward  $\text{NH}_3$ . Regarding  $\text{NO}_2/\text{NO}$  signal ratio, although the sensors based on commercial YSZ ink A sintered at  $1380^\circ\text{C}$  show the highest response to both gases, figure 5 shows that the most relevant sensor in regards of  $\text{NO}_2$  response is the one with YSZ B.



**Figure 4.** The responses of different sensors to 20 ppm of ammonia at  $450^\circ\text{C}$ .



**Figure 5.**  $\text{NO}_2/\text{NO}$  signal ratio of different sensors at  $450^\circ\text{C}$  (100ppm for each gas).

#### 4. Conclusion

Comparing all these results, it can be concluded that sensors made with home-made ink B give more confident results regarding  $\text{NO}_x$  and ammonia gases. Further investigations on chemical composition of these YSZ inks and structure of resulting electrolyte film will be performed in order to explain such different sensor responses.

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