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Development of an FET-based NH_3/NO_x sensor unit for SCR-control

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Abstract

This study concerns the tailoring of gas-sensitive FET sensor devices for the development of high-temperature NO_x and NH_3 sensors applicable for the control of urea-SCR when used as a NO_x abatement measure in automotive applications through the investigation of the interaction between different series of gas-sensitive materials and NH_3, NO, and NO_2 at different temperatures.

Key words: FET gas sensors, exhaust emissions monitoring, NH_3 sensing, NO_x sensing, SCR control

Background and motivation

As it has been concluded that a substantial number of type-approved diesel passenger cars still emit substantially more NO_x than legally permitted during normal driving, RDE (Real-Drive Emissions) testing has been introduced, whereby in-use vehicles are required to comply with the emissions limits also under real-world driving. To ensure fulfilment of the new regulations, the automotive industry urgently has to adopt much-improved exhaust after-treatment measures for diesel-, and for the future, other lean-burn vehicles than what is most often implemented today.

The NO_x emissions abatement measure generally considered most viable to fulfil the emissions legislation is urea-SCR (Selective Catalytic Reduction). Water-dissolved urea ($[NH_2]_2CO$) is dosed into the exhaust upstream the SCR catalyst, whereby the ammonia (NH_3) formed in the urea-decomposition reacts with any nitrogen oxides present in the exhaust on the surface of the catalyst. Close control of the urea dosing is necessary, however, since a deficiency of NH_3, compared to the exhaust NO_x concentration, will result in NO_x emissions, whereas excess urea dosing results in the emission of NH_3, which is one of the substances acting as precursor for formation of ultra-fine particles in the atmosphere. With the new emissions legislation and RDE requirements, on-line monitoring of the tailpipe-out NO_x and NH_3 emissions (downstream the catalyst) to fine-tune the urea dosing in a feedback control loop is therefore considered a very attractive solution to achieve the required level of SCR-control. Already today the dosing is based on the NO_x reading of a ZrO_2 solid electrolyte based sensor upstream the point of urea injection, a sensor which often also is used to monitor the NO_x concentration downstream the catalyst. Since this sensor also exhibits some sensitivity/ cross-sensitivity to NH_3 and no selective NH_3 sensor to date has been commercialized applicable for on-line exhaust monitoring, the development of a sensor unit able to selectively measure primarily NH_3, but also NO_x, with good sensitivity at low concentrations would be of interest.

The SiC-based Field Effect Transistor (FET) sensor platform, see Fig. 1, has previously been shown applicable for in-situ on-line emissions monitoring [1], and an NH_3 sensor has also been commercialized from the platform for ammonia slip monitoring in marine applications [2]. As determined by the sensor materials interacting with the exhaust NH_3, reasonable sensitivity and selectivity can for this existing sensor be found for operating temperatures in the range 275 to 350 °C, which is of less importance in marine applications but not that feasible for NH_3 monitoring in the automotive sector. So far also no FET-based sensor for exhaust NO_x measurements has been developed. This study was therefore conducted to investigate the possibility of developing and fabricating FET-based sensors for both NH_3 and NO_x monitoring at the kind of operating temperatures which would enable their use in automotive SCR-control.

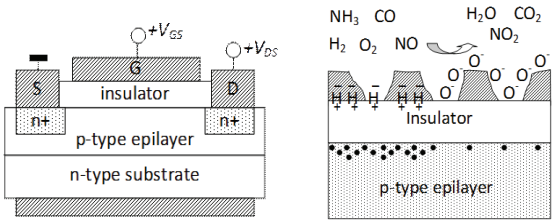

Fig. 1 displays a cross-section of the FET gas sensor device and the mechanism behind its gas-sensitivity

Experimental

The interaction of series of conceptually different materials which can be applied as part of the gate contact in FET devices, such as alkali-earth metals based titanate perovskites and transition metal oxides, with NH_3 and NO/ NO_2 at different temperatures were investigated through Temperature Programmed Desorption (TPD) and Mass Spectrometry as well as calorimetry and related to the corresponding observed changes in I/V-characteristics of field effect devices. From the adsorption/ desorption/ reaction interactions investigated at temperatures ranging from 200 to 700 °C, trends in the interaction between NH_3, NO, and NO_2, could be established for the series of materials, in relation to operation temperature.

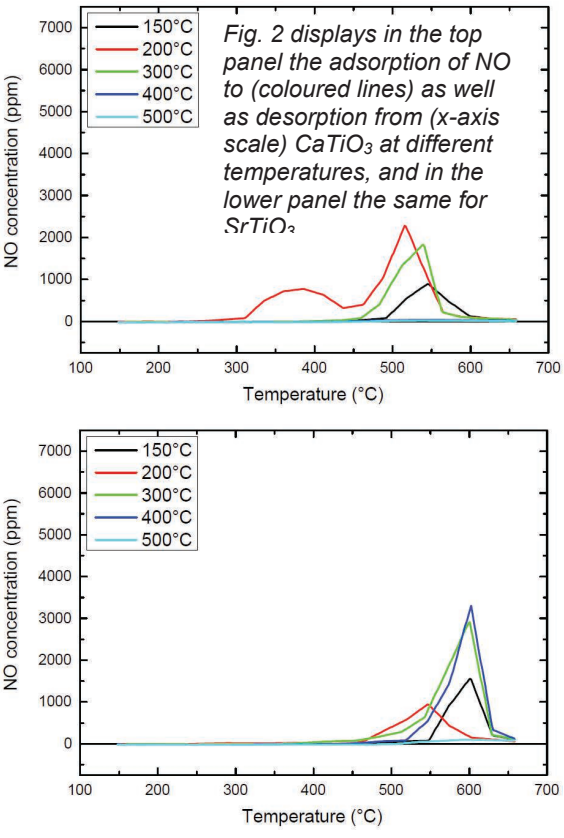

Fig. 2 displays in the top panel the adsorption of NO to (coloured lines) as well as desorption from (x-axis scale) $CaTiO_3$ at different temperatures, and in the lower panel the same for $SrTiO_3$

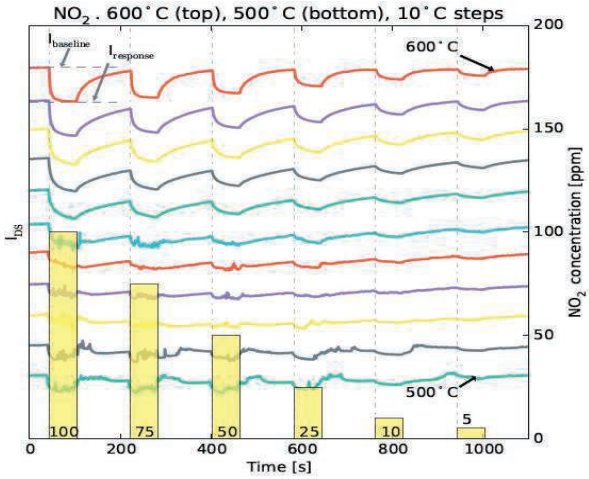

Fig. 3 displays the response of sensors employing $SrTiO_3$ as part of the gate material at different temperatures, ranging from 500 to 600 °C (bottom to top), to different concentrations of NO_x.

Results

An example of the results from the investigation of trends related to adsorption and desorption of NO to a series of Perovskite materials comprising of $MgTiO_3$, $CaTiO_3$, $SrTiO_3$, and $BaTiO_3$ is given for $CaTiO_3$ and $SrTiO_3$ in Fig. 2. As seen from these measurements, dynamic adsorption and desorption of NO occurs at about 600 °C for $SrTiO_3$, whereas adsorption and desorption of NO to $CaTiO_3$ occurs over a wider but generally lower range of temperatures. Adsorption/ desorption to/ from $MgTiO_3$ occurs at even lower and for $BaTiO_3$ at temperatures above 700 °C. As seen from Fig. 3, a good response to NO_x when employing $SrTiO_3$ as gas-sensitive material in the FET sensor is achieved for operating temperatures at or slightly below 600 °C. Through the application of NiO as part of the gas-sensitive material, it was also possible to shift the maximum sensitivity towards NH_3 to higher operating temperatures than 275-350 °C, in the range of 425-500 °C

References

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