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Performance Testing of a MOSFET Sensor

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1 Introduction

The widespread use of hydrogen as a fuel will bring new challenges in terms of safety and hydrogen safety sensors will therefore play an important role in such a hydrogen economy. Devices for the detection and quantification of hydrogen are well-established in controlled industrial and laboratory environments. In the future however, hydrogen safety sensors will be used more widely and under a greater range of ambient conditions for the protection of people and property. In this context, independent performance testing of such sensors is extremely important to ensure that they can accurately and reliably alert to the presence of hydrogen under the expected conditions of operation.

The sensor testing facility of the JRC-IE has been developed for this purpose and has previously been used in an extensive testing campaign involving a range of hydrogen sensing technologies [1]. Presented here are the results of tests on 2 identical commercially available MOSFET (Metal Oxide Semiconductor Field-Effect Transistor) sensors. These devices are field-effect transistors based on a triple layer structure consisting of a catalytic gate metal, an insulator (oxide) and a semiconductor layer. Adsorbed hydrogen molecules on the metal surface dissociate and diffuse to the metal-oxide interface where they produce a change in the electrical properties of the transistor, which can be correlated to the hydrogen concentration in the ambient atmosphere [2].

The performance of these sensors has been tested in terms of their accuracy, measuring range, cross-sensitivity to CO, as well as the influence of ambient temperature, pressure and relative humidity on their response. These results are compared with those obtained previously for a number of other sensor types.

2 Experimental and Results

The sensor testing facility (SenTeF) at the Institute for Energy of the JRC will be described briefly here, but a more detailed description is available in the literature [3,4,5]. It consists of a 2.4L test chamber in which sensors are mounted, a gas handling system, a control and data acquisition system and an independent gas analyzer, as well as subsidiary devices for temperature management and power supply. All electrical signals, including sensor input and output are transmitted to and from the chamber via two 25-pin feedthroughs. Gas is introduced into the bottom of the chamber and leaves from the top, while a fan is positioned inside the chamber to ensure homogeneity of gas composition and temperature. Gases are mixed online and humidified using a Bronkhorst® controlled evaporator mixer. Test gas humidity is measured using a chilled mirror dew point meter. The temperature in the chamber is controlled by circulating thermostatic fluid between the walls and is measured using three Pt100 thermometers. The actual composition of the gas in the chamber is monitored

continuously using a compact gas chromatograph (GC) calibrated to quantify hydrogen concentration.

A series of tests was carried out to assess the performance of these sensors:

1. Accuracy of response
2. Measuring range
3. Detection limit
4. Cross sensitivity to carbon monoxide (CO)
5. Ambient temperature
6. Ambient pressure
7. Ambient relative humidity

The procedure for carrying out these performance tests was developed based on that described in IEC 61779 and will be outlined briefly here, although more detail is available in the literature [3]. The standard test conditions for all tests were:

Temperature: 298 ± 2 K

Pressure: 100 ± 2 kPa

Relative humidity: 50% RH (dew point 13.8 ± 1.8 ºC)

Gas flow rate: 1000 ± 20 nml/min

In the ambient parameter tests, only the relevant parameter was varied and otherwise the conditions remained as above.

2.1 Sensors

The MOSFET sensors under test are commercially available devices, designed for installation in vehicles and hydrogen fueling stations. Relevant specifications given by the manufacturer are as follows:

Table 1: Technical specifications of MOSFET sensor.

Accuracy	± 3000 ppm
Measuring range	0 – 4.4% H2 in air
Operating temperature	-40 – 110ºC
Pressure	70 – 130 kPa
Humidity	5 – 95%
Cross sensitivity towards CO	None
Influence of humidity	None

2.2 Accuracy

Sensors were exposed to a gas mixture whose concentration was increased in a stepwise fashion from 0.0 to 2.0 vol% and then decreased in the same way. Control of the gas concentration was achieved by online mixing of 2 vol% hydrogen in air with synthetic air and the maximum concentration tested was 2 vol% for safety reasons. At each concentration, the sensor response and GC reading were allowed to stabilize before proceeding with the

subsequent step. This test was performed immediately before the measuring range test described below.

Results are shown in the left part of Figure 1. The two sensors gave almost identical responses. They are highly accurate, deviating by a maximum of 2020 ppm from the GC values over the range of hydrogen concentration investigated. Although the deviation of the sensor response in ppm increases steadily with increasing hydrogen concentration, this deviation as a % of the GC value decreases as the hydrogen concentration increases. Relative to the actual hydrogen concentration therefore, the accuracy of these sensors increases as the hydrogen concentration is increased within the range 0 – 2 vol%.

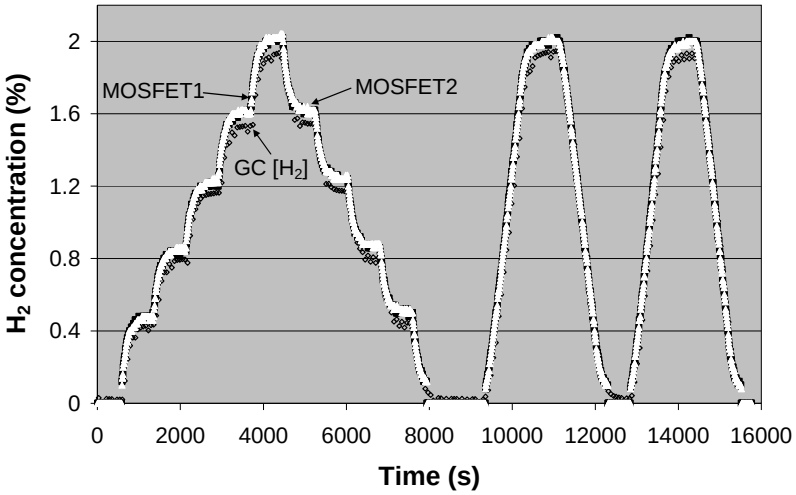

Figure 1: Results of accuracy and measuring range test.

2.3 Measuring range

The purpose of this test was to monitor the response of sensors to changing hydrogen concentration. The sensors were exposed to a test gas mixture which was increased steadily in concentration from 0.0 to 2.0 vol% H_2 and then decreased again. The process was repeated immediately in order to reveal any evidence of hysteresis or memory effects.

The results of the measuring range test are shown in the right hand part of Figure 1. In both cases, the sensor response increases and decreases in line with that of the GC and with no evidence of hysteresis.

2.4 Detection limit

The aim of this test was to determine the lowest concentration of hydrogen that these sensors were capable of detecting. The hydrogen concentration in the test gas was increased incrementally from 0.0 vol% until a definite increase in sensor output, distinct from baseline noise, was observed. However, the lowest concentration of hydrogen that could be accurately mixed during this test was 0.03 vol% and both sensors were found to give a well-defined response at this concentration. Therefore the detection limit could not be determined exactly, but must lie below 0.03 vol% H_2 in air.

2.5 Cross sensitivity to CO

The test gas consisted of a constant flow of 2.0 vol% H_2 in air and a mixture of synthetic air and 0.51 vol% CO in nitrogen. The relative flows of synthetic air and CO/N_2 were varied stepwise in order to control the concentration of CO in the test gas mixture. The CO concentration was varied until a deviation in the sensor signal equivalent to 0.4 vol% H_2 (10% LFL) was observed. The sensor cross sensitivity to CO is expressed here as the concentration of CO required to produce this signal deviation.

The response of these sensors to different concentrations of CO in a 1 vol% hydrogen/air mixture is shown in Figure 2. It can be seen that an increase in the CO concentration leads to a proportional decrease in the sensor signal. The deviation in both sensor signals from their readings in the absence of CO was –0.32% at the maximum CO concentration tested of 2540 ppm. Extrapolation of the data gives a signal deviation of 0.4 vol% at a CO concentration of 3150 ppm.

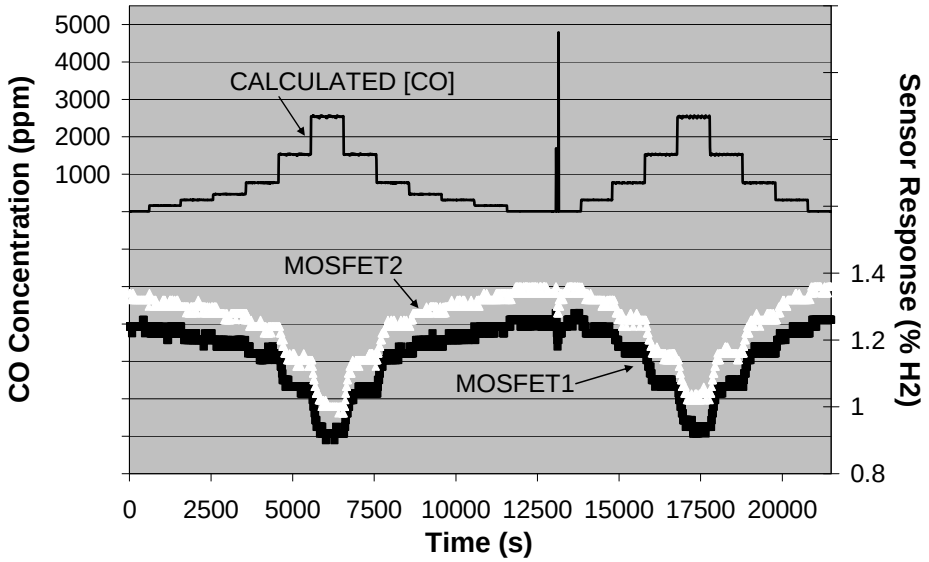

Figure 2: Results of CO cross-sensitivity test.

2.6 Ambient temperature

The purpose of this test was to examine the influence of temperature on the sensor signal in both the absence and presence of hydrogen. At each of five temperatures (-15, 5, 30, 60, 80ºC) within their operating range the sensors were exposed first to clean air and then to 2 vol% H_2 in air. There is no apparent influence of temperature on sensor response within the range -15 to 80ºC. Results of this test are shown in Figure 3.

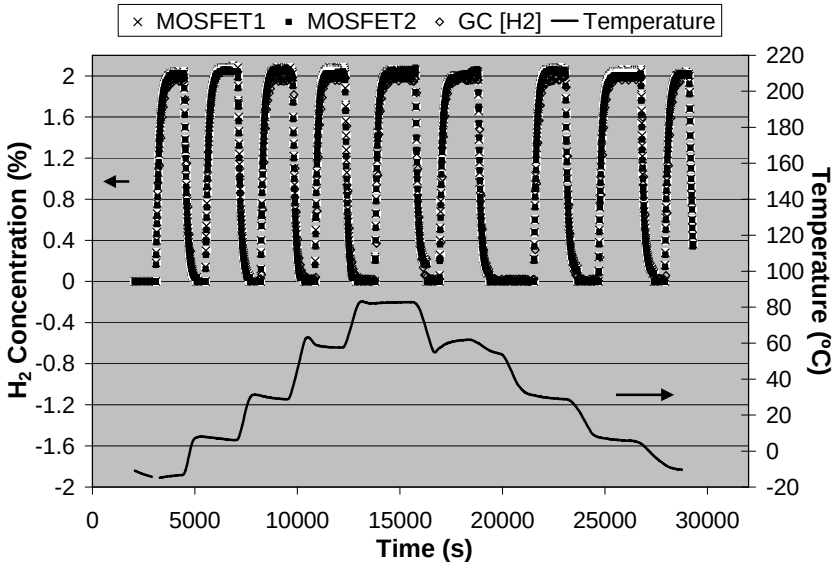

Figure 3: Results of temperature test.

2.7 Ambient pressure

Similar to the ambient temperature test method, the sensors were exposed to clean air followed by 2 vol% H_2 in air at a number of pressures (80, 90, 100, 120 kPa) within their operating pressure range as a means of determining the influence of ambient pressure on sensor response. As with temperature, there was found to be no detectable influence of pressure within the range tested.

2.8 Ambient humidity

In order to assess the influence of ambient humidity on sensor response, the sensors were exposed to clean air and then 2 vol% H_2 in air at a number of relative humidities (20, 40, 60, 80%) distributed over the operating range specified by the manufacturer. The sensor signal was found to be independent of humidity at both 0 and 2 vol% H_2 over the dew point range tested.

2.9 Comparison with other sensor types

An identical series of tests was previously carried out on a number of other sensor types[1]. In Figure 4 the performance of the MOSFET sensors tested in this work is qualitatively compared with that of the catalytic, electrochemical, metal oxide semiconductor and thermal conductivity sensors previously tested. For each test each sensor type was assigned a number between 0 and 4 to represent its relative performance. The MOSFET sensors tested here were found to perform as well or better than the other sensor types in all tests except for cross-sensitivity to CO.

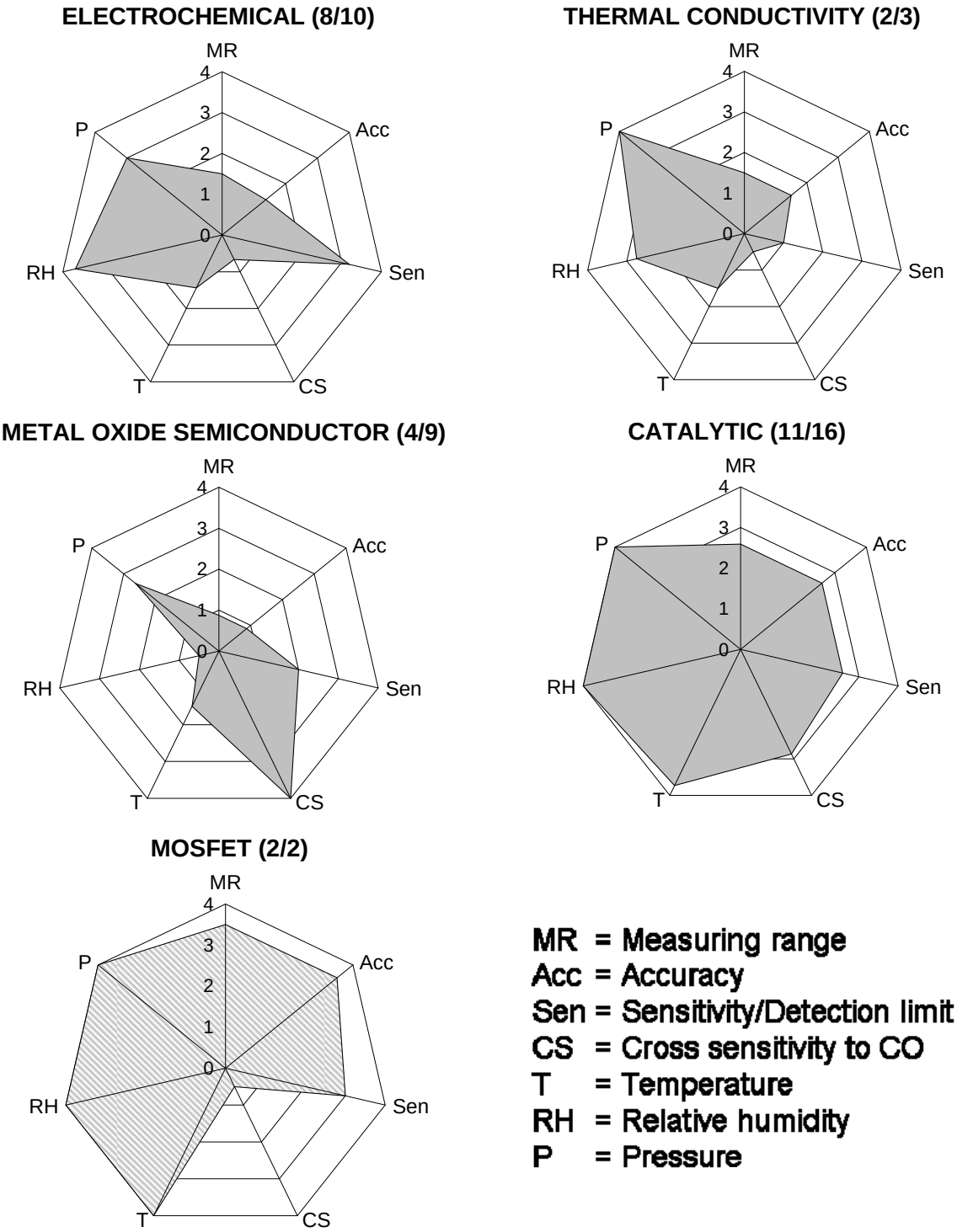

Figure 4: Qualitative summary of performance test results of MOSFET sensor compared with other sensor types. Numbers in brackets represent the ratio of the number of functioning sensors to the number of sensors purchased.

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