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SGP Testing Guide
For Sensirion's SGP Gas Sensors

Content

1 Introduction

The SGP testing guide provides guidelines and recommendation on testing concepts for metal-oxide gas sensors, in particular the SGP multi-pixel gas sensor. The first part of this documents introduces basic concepts of metal-oxide gas sensor technology and the SGP. The second part describes testing methods that do not require investment in dedicated measurement setup. For easy evaluation of the SGP Sensirion provides the SensorBridge evaluation kit. A more detailed evaluation of gas sensors requires a dedicated test setup that is able to expose the sensors to well-controlled gas mixtures. Such a system allows an in-depth characterization of the gas sensing properties. The corresponding test methods are covered in the third part of this document. The last part describes Sensirion's recommendation for a production line test.

2 SGP Basics

2.1 Metal-Oxide Gas Sensor

The sensing principle of the SGP is based on a heated film of metal-oxide (MOx) nanoparticles (see **Figure** 1). Adsorbed oxygen on the metal-oxide particles reacts with the target gas and thereby releases electrons. This results in a change of the electrical resistance of the metal-oxide layer that is measured by the sensor.

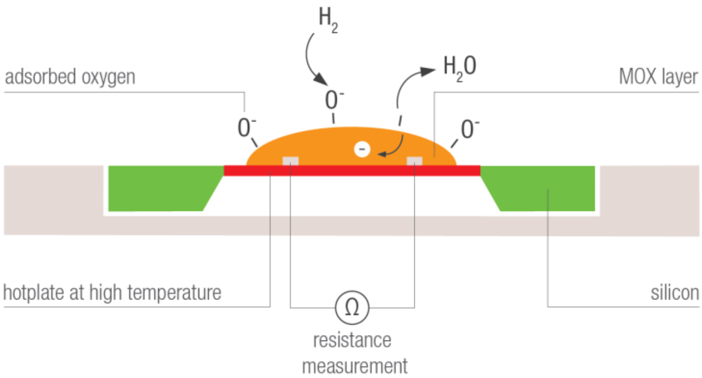

Figure 1 Sensing principle of the SGP multi-pixel gas sensor.

Gas sensors based on metal-oxide technology offer very high sensitivity to a wide range of gases including typical indoor air pollutants like volatile organic compounds or hydrogen. This is illustrated exemplarily for a number of different gases in **Figure 2**.

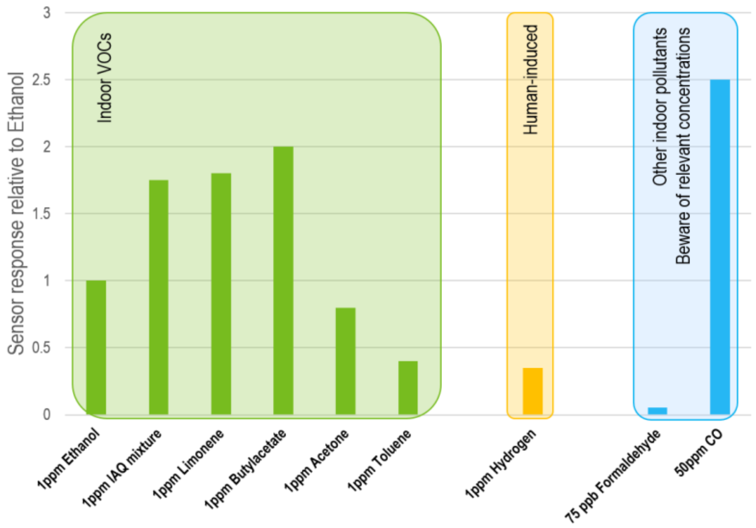

Figure 2 Response of the SGP30 to different indoor air pollutants.

2.2 The SGP Multi-Pixel Gas Sensor

The SGP multi-pixel gas sensor platform integrates four metal-oxide elements – the pixels – into one small DFN package. Using Sensirion's CMOSens® technology, the SGP offers a complete sensor system on a single chip featuring a digital I²C interface, a temperature-controlled micro-hotplate, as well as preprocessed and calibrated indoor air quality signals.

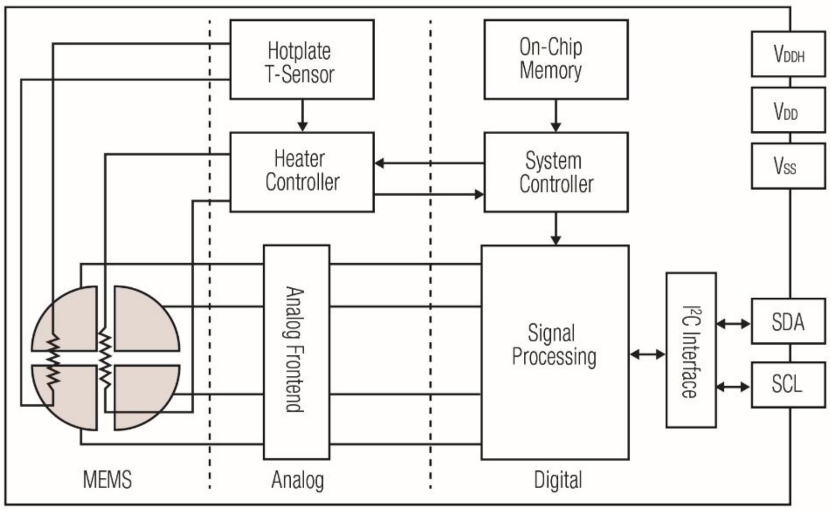

Figure 3 Functional block diagram of the SGP gas sensor.

2.3 Baseline Compensation Algorithm

The SGP features an on-chip baseline compensation algorithm that compensates long-term drifts of the sensor signal. The baseline algorithm uses the atmospheric hydrogen background in clean air (=VOC-free air) as a reference. The baseline compensation algorithm requires that the SGP is exposed to clean air in regular intervals. A short (~10 min) exposure to clean air once a week is sufficient. In most indoor applications the sensors will be exposed to clean air in regular intervals e.g. by automatic or manual ventilation. Therefore, operation of the SGP does not require any recalibration or maintenance.
For more details about the baseline compensation algorithm, please refer to the application note "*AN_SGP_Baseline_Start-up_Humidity*".

2.4 SGP Start-Up

All metal-oxide gas sensors require a certain stabilization time after start-up to allow the sensing layer to reach a stable chemically steady-state. The stabilization time depends on the time interval the sensor has been unpowered and the conditions (e.g. humidity) under which it was stored. Sensirion recommends to stabilize the SGP for a certain time before doing any experiments as summarized in **Table 1**.

off-time	SGP30 stabilization time
1 min	15 s
5 min	30 s
1 h	80 s
12 h	6 min
48 h	12 min
Initial start-up (new sensor)	50 min

Table 1 Stabilization times vs switch-off times.

2.5 SGP Output Signals

Based on Sensirion's multi-pixel technology, the SGP sensor provides a number of different output signals. As shown in **Figure 4** exemplarily for the SGP30 the input of the four sensing elements is used to generate different output raw signals (ethanol signal and hydrogen signal). These signals are used as input for the baseline compensation algorithm that calculates the air quality total VOC (TVOC) and CO2eq output signals (**Figure 4**). The gas sensing specifications in the datasheet and the performance characterization refer to the ethanol and hydrogen signals. For part verification and component evaluation we recommend to use the raw signals, while for application testing the air quality signals should be used.

2.6 SGP Calibration

The raw signal outputs of the SGP are calibrated to different calibration gases indicated by the name of the signal. From the sensor raw signal output a gas concentration for the calibration gas can be calculated as described in the datasheet and in section 4.2 of this document.
From the ethanol raw signal, a TVOC concentration is calculated by applying the baseline compensation and an additional calibration factor to convert the gas concentration from ethanol to TVOC. A standardized mixture of 22 VOCs[1] is used as a reference for this TVOC calibration factor.
Similarly, the hydrogen signal is used to determine the CO2eq output. Again, an additional calibration factor is used to convert the hydrogen concentration to a CO2eq concentration. This calibration factor has been determined by a large number of field tests correlating CO2 and hydrogen concentrations in different real-life situations.

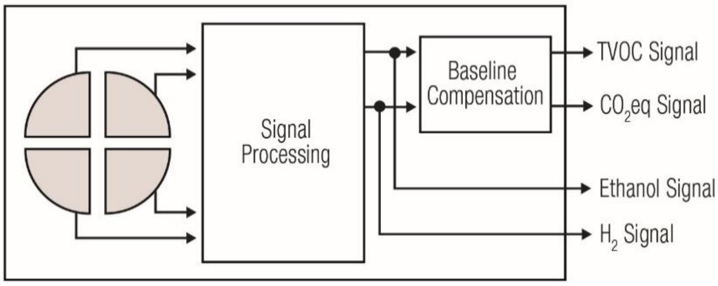

Figure 4 Simplified version of the functional block diagram showing the signal paths of the SGP30.

[1] Molhave et al., Human reactions to low concentrations of volatile organic compounds. Environ Int 12:167–175 (1986)

3 Real-Life Testing

3.1 Test setup

Sensirion provides an evaluation kit for an easy and cost-efficient evaluation of the SGP multi-pixel gas sensors. The evaluation kit combines a plug-and-play hardware (SensorBridge) with an easy-to-use viewer software (ControlCenter). Each SGP evaluation kit comes with several SGPxx and SHTxx sensors soldered on flex PCB and all required cables. The ControlCenter software can be downloaded from the Sensirion website.
The software allows to log the indoor air quality output signals of the SGP as well as the corresponding raw signals.

Figure 5 SGP evaluation kit SensorBridge

3.2 Test preparation

Before doing any experiments, the SGP sensor has to be operated for a certain time to stabilize its output (see section 2.4). The recommended stabilizations times are summarized in **Table 1**.
In addition, the SGP uses an on-chip baseline compensation algorithm to compensate long-term drifts of the sensor signal (see section 2.3 and application note *AN_SGP_Baseline_Start-up_Humidity*). When the SGP sensor is operated for the first time, the on-chip baseline compensation algorithm has to initialize the baseline. This is most easily done by exposing the sensor to clean air for at least 10 min during the first 12 h of operation. After the sensor has been operated for more than 12h for the first time[2], the baseline is stored by the ControlCenter software and will be reloaded every time the sensor is used with the same computer. Operating the same sensor with a different computer requires a reinitialization of the baseline.

3.3 Real-life Indoor Air Quality Signals

Testing

As a first evaluation test it is advised to run a use-case based field study. This allows an easy evaluation of the sensor without an investment in expensive gas laboratory equipment. It is advised to run the use-case based field study for several days in different environments like e.g. meeting rooms, offices, living rooms, apartments. It is also recommended to run several SGP sensors in parallel to evaluate the device-to-device variation.
Before starting the experiment, the sensors should be initialized as described in section 3.2.

Data Evaluation TVOC

Figure 6 Field study data of 10 SGP30 TVOC outputs (grey lines) and the median (green line) operated for several months in a meeting room. The different colors indicate different TVOC levels based on internationally recognized

[2] Alternatively, the current baseline can be stored directly without waiting for 12h by using the «force baseline" button in the ControlCenter software.

guidelines[3]. In most scenarios, regular TVOC peaks on top of a constant background will be observed. The peaks typically originate from human activities like e.g. cleaning, cooking, or meetings. The background signal is caused by the VOC background of the room which originates e.g. from furniture, carpets, or building materials.
The sensor needs to be exposed to clean air in regular intervals as described in section 2.3. In case the sensor has not been exposed to clean air for a long time (several weeks) the baseline will adjust to the VOC background of the room. Consequently, the sensor signal will show reduced TVOC levels. Exposing the sensor to clean air for a short time will readjust the baseline resulting in correct readings.

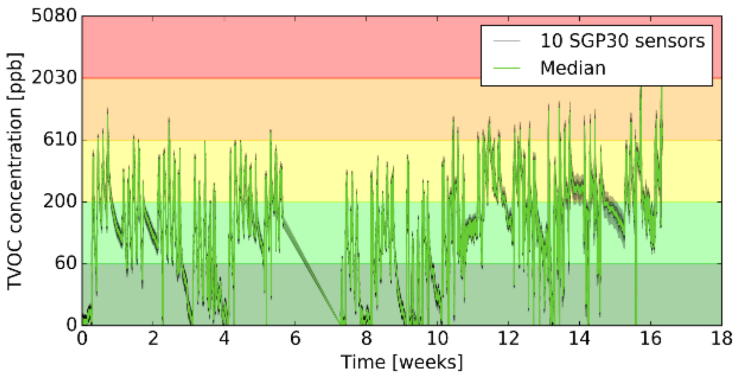

Figure 6 Field study data of 10 SGP30 TVOC outputs (grey lines) and the median (green line) operated for several months in a meeting room.

Data Evaluation CO2eq

In addition to the TVOC signal, the SGP30 provides a second air quality signal – the CO2 equivalent. The CO2eq is an estimate of the CO2 concentration based on a hydrogen measurement. The SGP does not measure CO2 itself. The best way to test the CO2eq is to operate the SGP30 for at least one week in a room with regular human presence (e.g. meeting rooms, offices, class rooms). **Figure 7** and **Figure 8** show an example of the CO2eq output of an SGP30 operated in a meeting room for several months. For comparison, the signal of an optical CO2 sensor (NDIR based) is shown as well. The data shows a good correlation between the two signals which is stable over several months. In situations where air pollution is dominated by human presence a good correlation between the H2-based CO2eq and the real CO2 is expected. The residual cross-sensitivity of the CO2eq signal to VOCs will result in CO2eq signals not observed in the real CO2 in situations where the sensor is exposed to large VOC concentrations.

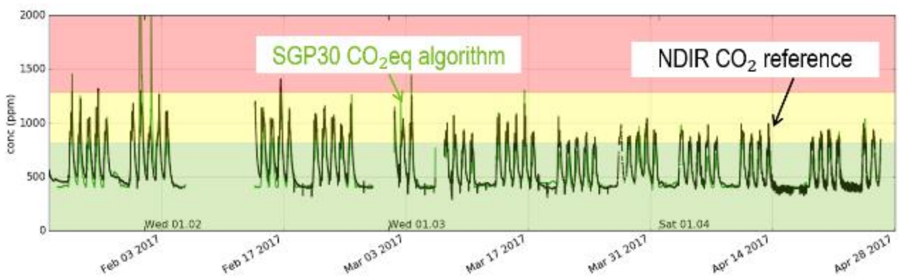

Figure 7 CO2eq output of the SGP30 (green curve) vs. optical (NDIR) CO2 reference (black curve) operated for several months in a meeting room. The colored background indicates air quality levels based on international building ventilation guidelines (IDA levels, EN13779).

[3] Federal Ministry of Health (Germany): Bundesgesundheitsbl - Gesundheitsforsch - Gesundheitsschutz 2007, 50:990–1005

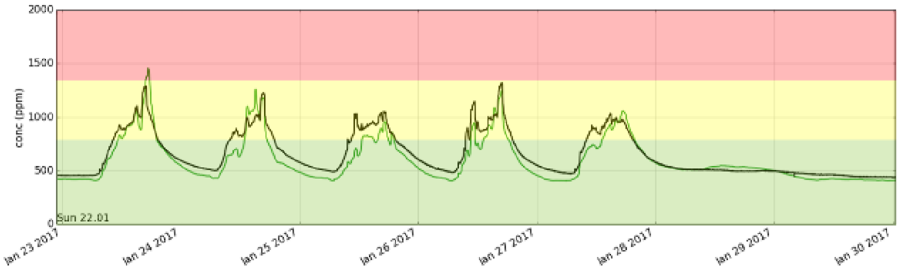

Figure 8 Detailed view of the field data from Figure 7 showing the CO2eq output of the SGP30 for one week.

3.4 Device-to-Device Variation

The easiest way to assess device-to-device variation is to operate several SGP sensors in the same location for several days. The ControlCenter Software allows to operate several evaluation kits in parallel. An example of 10 SGP30 operated in a meeting room is shown in **Figure 9** Detailed view of the field data from Figure 6 showing the TVOC output of 10 SGP30 during one week. demonstrating the low device-to-device variation of the SGP. The expected device-to-device variation of SGP sensors is specified in the respective datasheet. A detailed test and evaluation method is described in section 4.3 of this document.

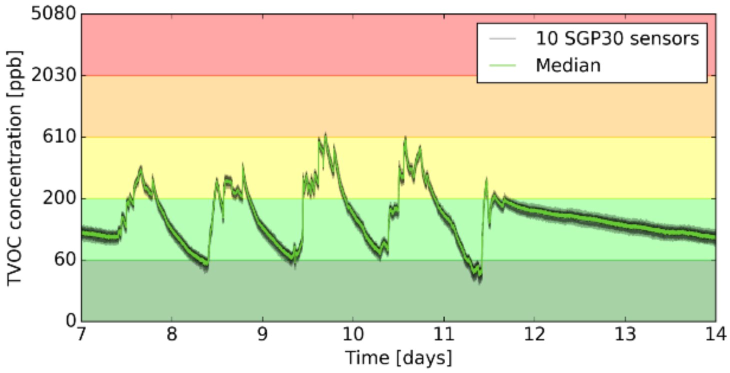

Figure 9 Detailed view of the field data from Figure 6 showing the TVOC output of 10 SGP30 during one week.

3.5 Accelerated Lifetime Test

Accelerated aging using a degradation box. This test is designed as an easy-to-use tabletop replacement of the siloxane accelerated lifetime test (see section 4.4). For the stress test the sensors are operated for 1-2 weeks in a closed box that contains various rubber products e.g. soft mobile phone covers (**Figure 10**). This test allows to quickly access the siloxane resistance of MOx sensors.
A detailed characterization of the sensor before and after the stress test requires a gas mixing system as described in section 4.1. However, a basic sensor evaluation can be done using the degradation box and a solution of water and ethanol as gas reference. The test procedure is summarized in **Table 2**. A more detailed description can be found in the application note "*MOx Sensor Hands-On Accelerated Lifetime Test*".
Please note that the table-top test is not recommended when highly reproducible and stable stress conditions are required e.g. for a part approval.

Figure 10 Example of a degradation box setup. The box has a volume of approx. 10l. The rubber parts are standard commercially available mobile phone covers.

Step	Table-Top Siloxane Stress Test
1	operated sensors as described in section 3.2
2	prepare test solution: ~1ml ethanol in 1000 ml water
3	- empty the degradation box - place beaker with test solution in the degradation box
4	operate sensors in the closed degradation box to determine their ethanol signal before the stress test
5	remove test solution and place rubber parts in the degradation box
6	**operate** sensors for 1-2 weeks in the closed box
7	repeat steps 2 and 3 to determine the ethanol signal after the stress test
8	compare ethanol signals before and after the test

Table 2 Step-by-step test procedure for the table-top siloxane stress test.

3.6 Design-in Test

Similar to other environmental sensors a few design-in rules have to be considered when integrating the SGP into a device. These recommendations are summarized in the application note "*SGPxx-Design-In Guide*". The easiest way to test the design-in is to operate the device with the integrated SGP and use an SGP with an evaluation kit as a reference. Make sure to stabilize the sensor output before the experiment as described in section 2.4. Place the device with the SGP and the reference SGP in the same location (e.g. an apartment or a meeting room) and operate both for several days. With a good design-in both sensors should show similar output signals. Significant deviations between the two sensors can indicate a problem with the mechanical design-in or the software implementation of the SGP driver. A list of commonly observed design-in problems is shown in **Table 3**.
In addition, a test of the local VOC background at the intended sensor position is recommended. Again, an SGP on flex PCB which is delivered with the SGP evaluation kit can be used as a reference. To measure the VOC background inside the device the TVOC signal inside the device and in ambient air should be recorded. A similar TVOC output of the same SGP in both situation indicates a good design-in with a low VOC background.

symptom	possible reason	recommended solution[4]
smaller signals compared to the reference sensor	strong VOC background in the device caused by outgassing of materials or strong heat sources near the sensor	- good coupling to the ambient - good sealing to the inside - low outgassing materials - improved placement of the sensor inside the device
slower response time compared to the reference sensor	bad coupling of the sensor to the ambient. This can be caused by placing the sensor behind a too small opening or at a too large distance to the opening.	- optimized geometry to improve coupling to ambient air
spurious signals not observed in the reference sensor signal	switching on and off of heat sources or ventilators inside the device	- optimized coupling to ambient and improved sealing to the inside
noisy signal	- very noisy voltage source - no decoupling capacitors	- improved power supply

Table 3 Design-in test interpretation

[4] Please refer to the application note "*SGPxx-Design-In Guide*" for more details

4 Component evaluation

4.1 Test setup

To perform a component evaluation, a dedicated gas mixing system is required that is able to provide well-defined gas concentrations of Ethanol and Hydrogen in the concentration range from 0.3 ppm to 30ppm. In addition, the gas mixing system has to be able to control the humidity of the gas mixture. In order to allow accurate measurements of sub-ppm gas concentrations, special care has to be taken to avoid spurious signals caused by unwanted outgassing of VOCs from the gas mixing system components or measurement chambers.
Sensirion has developed a compact and easy-to-handle gas mixing system that is able to provide well-defined gas concentrations and humidities (see **Figure 11** and **Figure 12**). In addition, Sensirion has developed dedicated highly clean measurement chambers for gas sensors with small dead volumes that enable characterization of short response times and minimize VOC outgassing. For more information on the gas mixing system, please contact Sensirion directly.

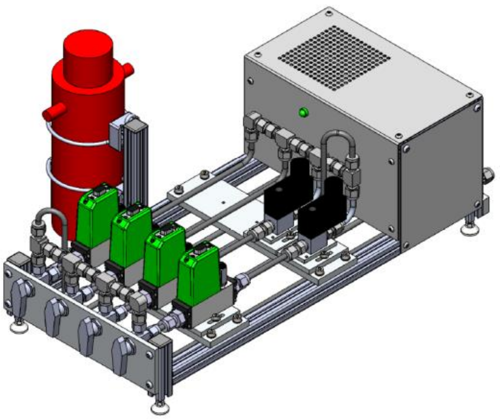

Figure 11 Drawing of the Sensirion gas mixing system with mass flow controllers (green) and humidifier (red)

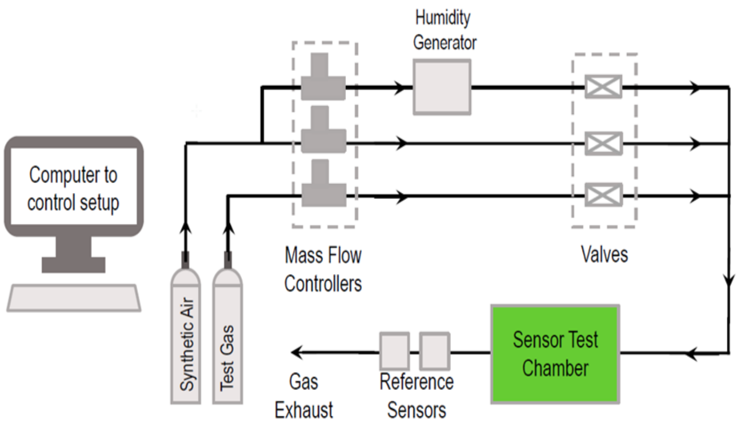

Figure 12 Schematic of the Sensirion gas mixing system. The reference sensors include a humidity sensor and a mass flow sensor.

4.2 Data Evaluation

Gas Concentration

The measured sensor output s_{out} is converted to a gas concentration c using the following formula

$$ln\left(c/c_{ref}\right) = \frac{(s_{ref}-s_{out})}{a} \quad (1)$$

with s_{out} the EthOH/H2 signal output at concentration c, s_{ref} the EthOH/H2 signal output at 0.5 ppm H2, and a=512. The concentration c_{ref} is a calibration parameter as defined in the datasheet.

Accuracy Tolerance

From the measured concentrations an accuracy tolerance is calculated defined as

$$accuracy\ tolerance = \frac{c-c_{set}}{c_{set}} \quad (2)$$

with c_{set} the gas concentration set point and c the measured concentration calculated from the sensor output as described above.

Accuracy Drift

From the pre- and post-characterization data the accuracy is calculated as described above. Then, the accuracy drift for the stress test is calculated by

$$accuracy\ drift = \frac{c_{post} - c_{pre}}{c_{pre}} \quad (3)$$

with c_{pre} and c_{post} the measured concentration values before and after the stress test, respectively.

Response Time

To determine the response time of a metal-oxide gas sensor, the sensor output has to be converted first to a gas concentration. For the SGP this is done using equation (1). The response and recovery time are determined by calculating the τ_{63} and τ_{37} time constants.

4.3 SGP Accuracy Testing

Characterization Sequence

The test sequence consists of 24 hours of run-in operation, where the samples are operated. During this run-in phase the sensors are exposed to clean air which is defined as 0.5 ppm of H2 with 50% relative humidity at 25°C in zero air[5]. After this initial run-in, the sensors are exposed to Ethanol and H2 concentration steps (45 min) as defined in **Figure 13**.
For each concentration step, the sensor output (s_{out}) is recorded at the end of each step (blue circles for Hydrogen signal, green circles for Ethanol signal). The baseline (s_{ref}) is measured at the end of the initial 0.5 ppm H2 step (red circle).

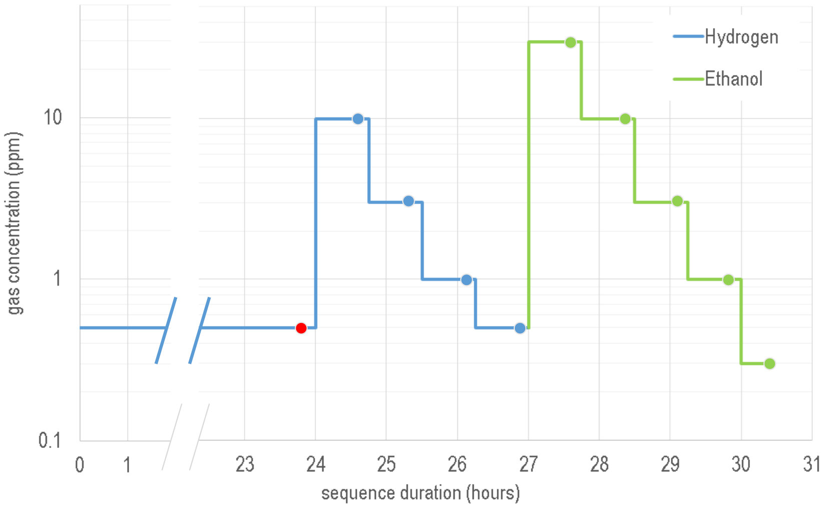

Figure 13 Sensor characterization gas sequence. All measurements are performed at 25°C and 50% relative humidity. For the calculation of the accuracy, the sensor output s_{out} at the end of each gas step is used (blue circles for Hydrogen and green circles for Ethanol). The baseline s_{ref} is taken at the end of the 24h clean air phase (red circle).

Example Data

As an example, the accuracy tolerance for the Ethanol and H2 signal of 80 SGP30 sensors is shown in **Figure 14**.

[5] Zero air is defined as laboratory high grade purified air, stripped of particles, hydrocarbons, carbon monoxide, nitrogen and sulfur oxides, ozone and humidity. It is defined by the EPA as purified air with less than 0.1 ppm total hydrocarbons.

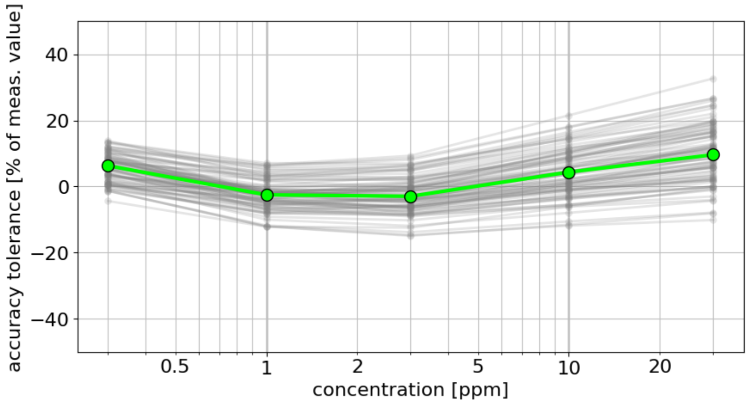

Figure 14 Accuracy tolerance Ethanol signal characterization at 25°C, 50% relative humidity, and typical Vdd.

4.4 SGP Siloxane accelerated lifetime test

Measurement Sequence

The siloxane accelerated lifetime test is designed to simulate aging of the sensor during 10 years of operation in indoor environments. The test procedure is summarized in **Figure 15**. Sensirion recommends two types of degradation tests depending on the available equipment and requirements regarding reproducibility of the test conditions. The pre- and post-characterizations are done similar to the accuracy testing described in section 4.2 and **Figure 13**.

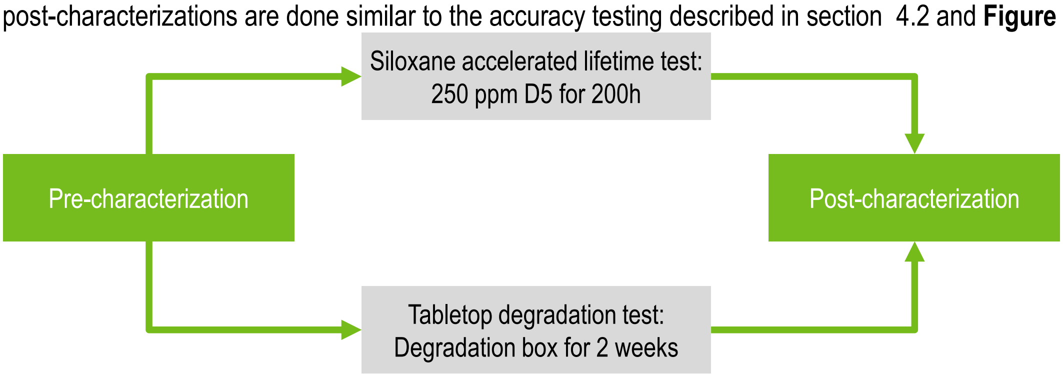

Figure 15 Siloxane degradation test procedure. Siloxane accelerated lifetime test or table-top degradation test.

The siloxane accelerated lifetime test

Operation of the sensors for 200h in 250 ppm Decamethylcyclopentasiloxane (D5).
Sensirion uses a dedicated gas mixing system for the Siloxane stress test which is able to provide well-defined concentration of 250 ppm D5. The D5 flow is created using a bubbler with liquid D5. Alternatively, the siloxane degradation box described in section 3.5 can be used instead of the D5 siloxane bubbler. The siloxane concentrations inside the box are however significantly lower than 250 ppm and will slowly decrease over time. The degradation box should therefore only be used for a general assessment of the siloxane degradation resistance of MOx sensors. During the 200h stress test, the SGP30 samples are exposed to a constant gas flow of zero air (200 ml/min) at 50% relative humidity and a concentration of 250 ppm D5. To ensure a realistic aging of the sensors, it is crucial that during the stress test the sensors are operated in their target operation mode

Example Data

Accuracy drift of 27 SGP30 sensors operated for 200h in 250 ppm Decamethylcyclopentasiloxane (D5). The test simulates 10 years of sensor operation in indoor conditions[6]. A siloxane resistant sensor should show only minor changes of its sensing properties between the pre- and post-characterization as reflected by a low accuracy drift as shown in **Figure 16**. Typical signs of degradation are a loss of sensitivity to most gases except for hydrogen and an increase of the response time.

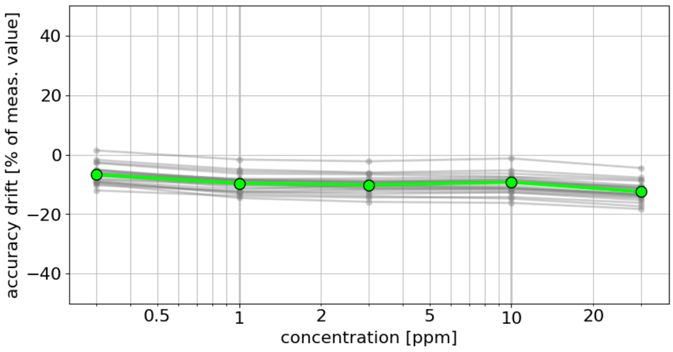

Figure 16 Long-term stability Ethanol signal. Accuracy drift after operation in 250 ppm D5 for 200h. This stress test simulates 10 years of operation in typical indoor conditions.

4.5 Response and Recovery Time

Response Time Characterization Procedure

All samples are subjected to a standardized gas sequence for response and recovery time characterization. The sequence consists of at least 24 hours of run-in operation as defined in section 4.3. The samples are then subjected to a step change in ethanol concentration from 0.3 ppm to 30 ppm and back. The measurement setup and in particular the dead volume of the measurement chamber is designed in such a way that the gas concentration at the sensor changes in less than 1s.

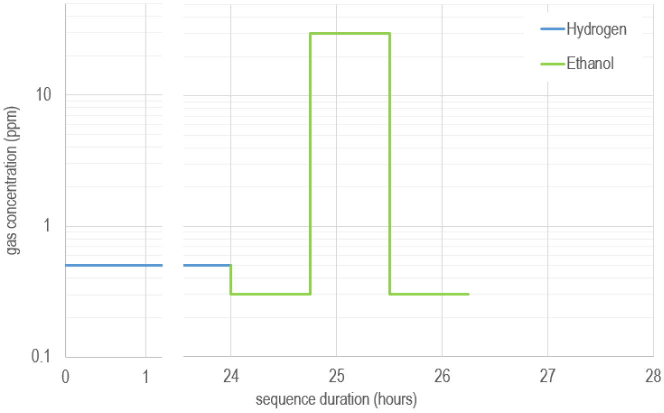

Figure 17 Response and recovery time characterization sequence

[6] Indoor conditions are defined as a siloxane concentration of 40 ppb.

Example Data

Response time and recovery time characterization of 32 SGP30 samples. **Figure 18** and **Figure 19** show the median of the normalized response to a concentration step from clean air to 30 ppm and from 30 ppm to clean air.

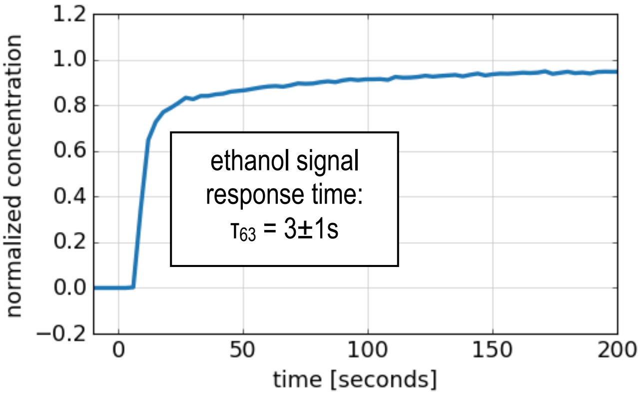

Figure 18 Response time ethanol signal. Normalized response to a gas concentration step from clean air (0.5 ppm H2) to 30 ppm ethanol.

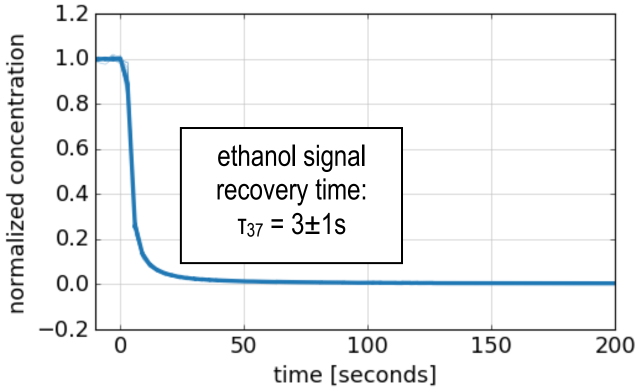

Figure 19 Recovery time ethanol signal. Normalized response to a gas concentration step from 30 ppm ethanol to clean air (0.5 ppm H2).

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5 Production line testing

At this point, for a smooth integration of the Sensirion SGP gas sensor, it is advised to read the application note *Handling and Assembly of Sensirion SGP Gas Sensors* up front.
Like all Sensirion products, every single SGP gas sensor is fully calibrated and tested before shipment. These tests include a sensitivity check to a set of defined gases as well as an electrical and optical test. This guarantees the best performance for every single shipped sensor and drastically reduces the amount of testing needed at the customer site.
With the Sensirion SGP gas sensors the production line testing is reduced to one quick test. This test will ensure proper electrical connection of the SGP and that the sensor was not damaged during mounting. To run such a test, the Sensirion SGP gas sensor comes with an on-chip self-test. The "*Measure_test"* command, as described in the datasheet, starts the self-check and will return "0xD400" if all internal tests were passed. It is that simple.

6 Important Notices

6.1 Warning, Personal Injury

Do not use this product as safety or emergency stop devices or in any other application where failure of the product could result in personal injury. Do not use this product for applications other than its intended and authorized use. Before installing, handling, using or servicing this product, please consult the data sheet and application notes. Failure to comply with these instructions could result in death or serious injury.

If the Buyer shall purchase or use SENSIRION products for any unintended or unauthorized application, Buyer shall defend, indemnify and hold harmless SENSIRION and its officers, employees, subsidiaries, affiliates and distributors against all claims, costs, damages and expenses, and reasonable attorney fees arising out of, directly or indirectly, any claim of personal injury or death associated with such unintended or unauthorized use, even if SENSIRION shall be allegedly negligent with respect to the design or the manufacture of the product.

6.2 ESD Precautions

The inherent design of this component causes it to be sensitive to electrostatic discharge (ESD). To prevent ESD-induced damage and/or degradation, take customary and statutory ESD precautions when handling this product.
See application note "ESD, Latchup and EMC" for more information.

6.3 Warranty

SENSIRION warrants solely to the original purchaser of this product for a period of 12 months (one year) from the date of delivery that this product shall be of the quality, material and workmanship defined in SENSIRION's published specifications of the product. Within such period, if proven to be defective, SENSIRION shall repair and/or replace this product, in SENSIRION's discretion, free of charge to the Buyer, provided that:

- notice in writing describing the defects shall be given to SENSIRION within fourteen (14) days after their appearance;
- such defects shall be found, to SENSIRION's reasonable satisfaction, to have arisen from SENSIRION's faulty design, material, or workmanship;
- the defective product shall be returned to SENSIRION's factory at the Buyer's expense; and
- the warranty period for any repaired or replaced product shall be limited to the unexpired portion of the original period.

This warranty does not apply to any equipment which has not been installed and used within the specifications recommended by SENSIRION for the intended and proper use of the equipment. EXCEPT FOR THE WARRANTIES EXPRESSLY SET FORTH HEREIN, SENSIRION MAKES NO WARRANTIES, EITHER EXPRESS OR IMPLIED, WITH RESPECT TO THE PRODUCT. ANY AND ALL WARRANTIES, INCLUDING WITHOUT LIMITATION, WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE, ARE EXPRESSLY EXCLUDED AND DECLINED.
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SENSIRION does not assume any liability arising out of any application or use of any product or circuit and specifically disclaims any and all liability, including without limitation consequential or incidental damages. All operating parameters, including without limitation recommended parameters, must be validated for each customer's applications by customer's technical experts. Recommended parameters can and do vary in different applications.
SENSIRION reserves the right, without further notice, (i) to change the product specifications and/or the information in this document and (ii) to improve reliability, functions and design of this product.

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