

Application Note

Using the Integrated Heater of SHT4x for Heat-Assisted Polymer Decontamination

Abstract

Polymer-based capacitive humidity sensors are often susceptible to contamination by certain volatile organic compounds (VOCs). In principle, contamination can be successfully prevented by following recommended handling instructions [1]. However, under certain conditions, VOCs can diffuse into the sensing polymer and influence the relative humidity signal. To remove contamination, the integrated on-chip heater of the SHT4x can be used to outgas contaminating VOCs from the polymer. This document outlines the working principle of polymer-based capacitive humidity sensors and theoretically explains and illustrates how contamination can influence the normal operation of the sensor. It then shows how the relative humidity signal of different sensors can be corrupted by an on-purpose VOCs contamination. Afterwards, the curing of the polymer utilizing the integrated heater is demonstrated, showing that the sensor can be fully restored to perform within original accuracy specifications after a heating period. In the end, best-practices for heat-assisted decontamination of SHT4x employing its internal heater are outlined.

Contents

1	Working Principle of Polymer-Based Capacitive Humidity Sensors	2
2	Contamination of Polymer-Based Capacitive Humidity Sensors	2
3	Acetone Contamination and Decontamination Process.....	4
4	Limitations and Recommendations for Heat-Assisted Contamination Removal	5
5	Further Information	6
6	Revision History	6
7	Bibliography	6

1 Working Principle of Polymer-Based Capacitive Humidity Sensors

In general, polymer-based capacitive humidity sensors are composed of two electrodes separated by a polymer, thus forming a capacitor. The structure and composition of the applied polymer enables for water absorption at dedicated binding sites. The higher the relative humidity (RH) in the measuring environment, the more water molecules will diffuse into the polymer and occupy the binding sites. When water molecules penetrate the polymer, they effectively change the relative permittivity ϵ_r and thus the capacitance $C \sim \epsilon_r$ of the system, yielding:

$$RH \sim C \sim \epsilon_r$$

A schematic of a typical humidity sensor realization is shown in **Figure 1**, depicting how the electrodes span their electric field lines through the polymer-mediated dielectric. Water binding sites in the polymer are occupied in a dynamic equilibrium between water ab- and desorption from the ambient. Equilibrium- or response time of such humidity sensors is determined by (i) polymer thickness (fixed), (ii) diffusion constant of the polymer and (iii) temperature. The latter shall be exploited further down in this text.

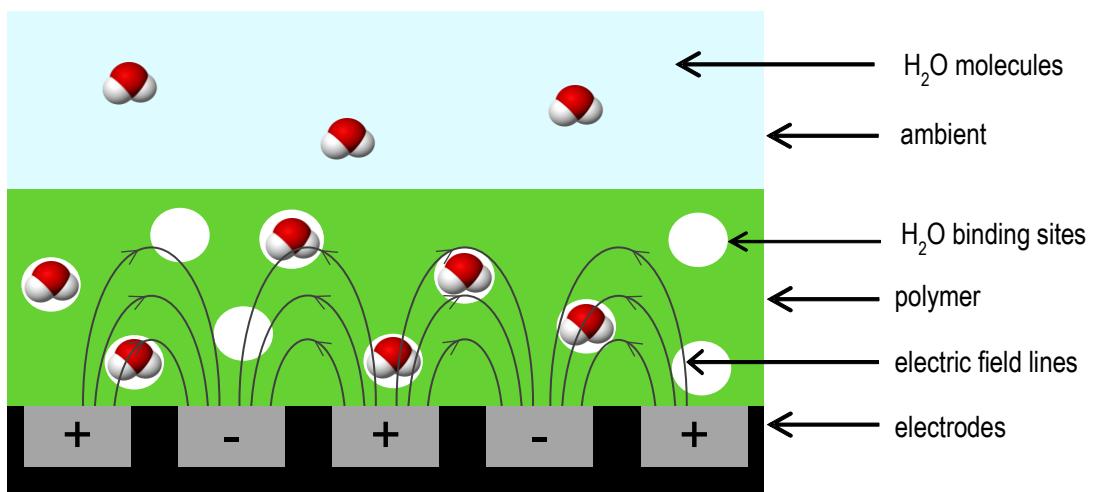


Figure 1: Cross-section and physical working principle of polymer-based humidity sensors using interdigitated electrodes (schematic, not to scale). Water molecules from the ambient penetrate the binding site influencing electric field lines.

2 Contamination of Polymer-Based Capacitive Humidity Sensors

Moisture-susceptible polymers are quite generally also susceptible to diffusion of other (small) volatile molecules. The absorption of molecules other than water is commonly adverse for the sensor measurement performance. In fact, there are distinct cases where the sensor accuracy is negatively affected by it, as shown in **Figure 2**. Here, different scenarios are outlined where diffusion of non-water molecules unfavorably impacts the calibrated sensor readout. For reference, the standard environmental conditions are represented in **Figure 2 (a)**, where no contaminants are present. In this case, the overall relative permittivity ϵ_r seen by the electrodes will only be dependent on the amount of water molecules absorbed by the polymer.

The presence of a volatile contaminant such as acetone in ambient is considered in **Figure 2 (b)**. The contaminant will diffuse along with water into the polymer until an equilibrium is reached. This leads to an alteration of the sensor output for two reasons. First, the overall relative permittivity ϵ_r seen by the electrodes is now influenced by the presence of the contaminant which has a relative permittivity $\epsilon_{r, \text{Contaminant}} \neq 1$. Second, the acetone is now competing with water for the occupation of the binding sites, thus potentially limiting the amount of water that can bind inside the polymer. Finally, **Figure 2 (c)** shows an extreme situation where the contaminant is occupying all binding sites within the polymer. In that case, the relative permittivity ϵ_r seen by the electrodes cannot be altered by the ambient water content, leaving the sensor blind to changes of ambient humidity. The relative permittivity ϵ_r seen by the electrodes is the polymer's relative permittivity $\epsilon_{r, \text{Polymer}}$ influenced only by the contaminant's relative permittivity $\epsilon_{r, \text{Contaminant}}$, and it remains constant at a value defined by the total amount of contaminant.

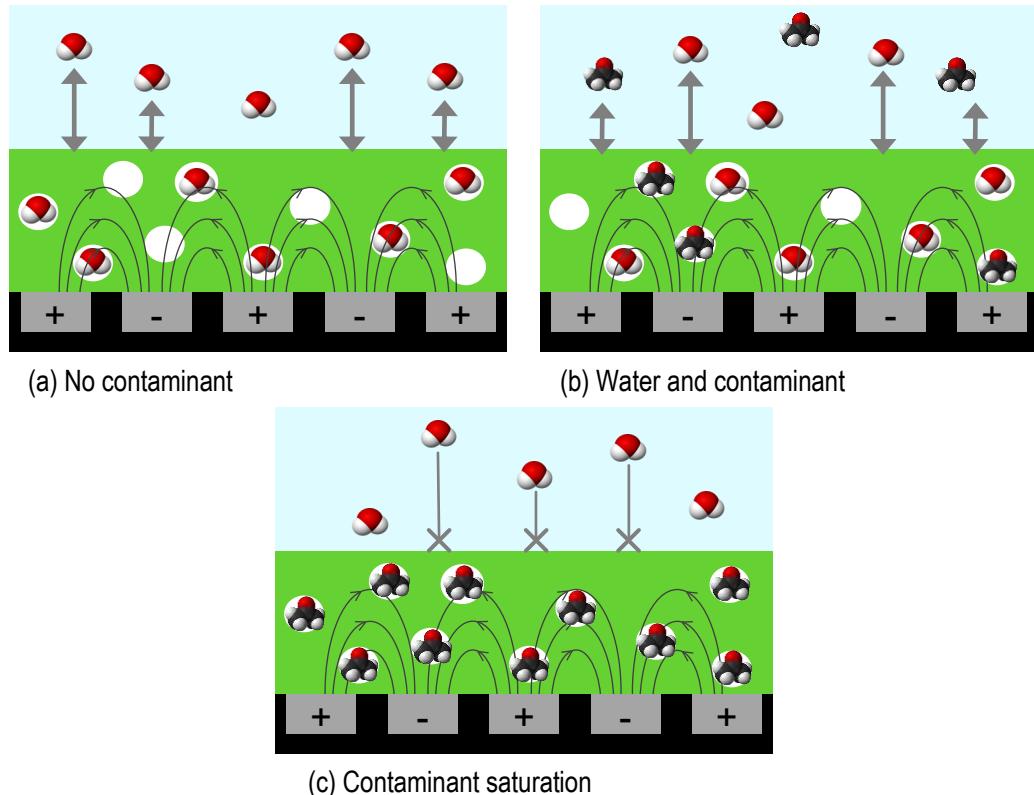


Figure 2: Schematic illustration of different contamination scenarios. (a) In standard conditions, only water is present. (b) If water and a volatile contaminant are present in the ambient, they will both interact with the polymer. (c) Certain contaminants lead to a full occupation of all water binding sites and are therefore largely hindering water molecules from entering the polymer.

The different contamination scenarios yield distinctive sensor response curves as outlined in **Figure 3**. The dashed black reference line corresponds to the regular sensor response, since no contamination is present. The solid blue line represents a contaminated sensor. Depending on the type and concentration of the contamination, the readout curve of a contaminated sensor may demonstrate an altered offset and slope. The dotted orange line represents a fully contaminated, blind sensor, where all the polymer's water binding sites are occupied by the contaminant. The relative humidity readout therefore remains constant regardless of the external environment. Note that the level of the constant RH readout can reach different values depending on the relative permittivity of the contaminant.

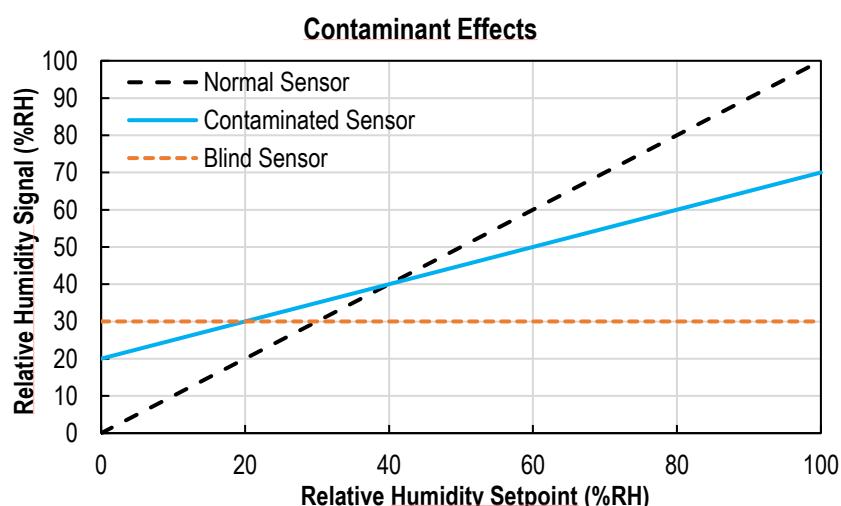


Figure 3: Relative humidity signal versus relative humidity setpoint. The normal sensor response (dashed black) is compared to sensor responses for different contamination scenarios (blue solid and orange dotted). Values for blue solid and orange dotted lines are arbitrary and chosen for best illustration.

3 Acetone Contamination and Decontamination Process

If, although following the handling instructions [1], contamination cannot be prevented, this section shows how it might be removed afterwards. One way is using the on-chip heater of Sensirion's SHT4x humidity sensor to effectively remove acetone contamination.

To illustrate the occurrence, impact, and persistence of acetone contamination, three commercially available capacitive humidity sensors are used. Here, a batch of SHT4x, competitor A, and competitor B are each purposely contaminated by exposure to a saturated acetone atmosphere at 25 °C for 20 hours. It shall be noted that this contamination procedure is very severe and seldomly found in real world scenarios, however it serves an illustrative purpose here. After acetone exposure, the sensors are continuously measured at fixed climate conditions (34% RH, 25 °C) over a period of two weeks, shown in **Figure 4**, to monitor the persistent offset induced by contamination. Although for some sensors the offset is decreasing with time, the ambient thermal energy is not sufficient to entirely outgas all acetone molecules. Thus, the sensors keep exhibiting a varied offset, clearly rendering them outside of typical accuracy specifications even after more than two weeks.

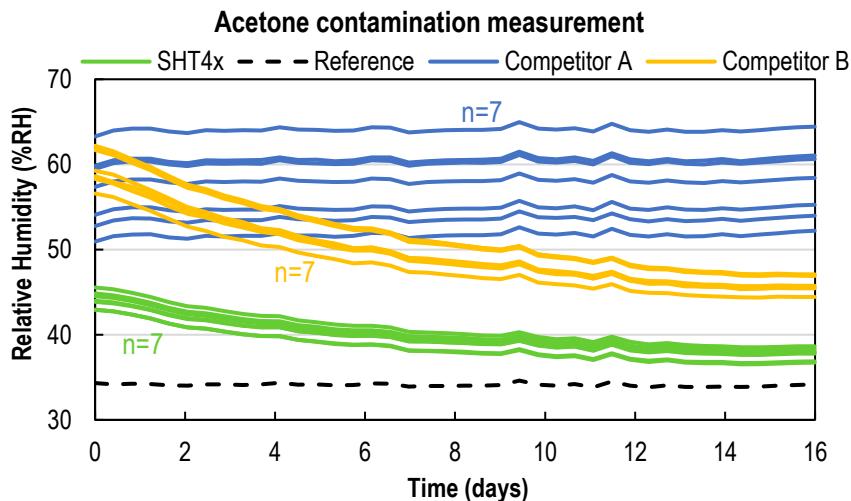


Figure 4: Three batches, each comprising of 7 pieces of capacitive polymer-based humidity sensors from different manufacturers are shown. Insufficient recovery of sensor humidity signals after contamination at ambient conditions. The contamination event is not shown in the plot. Some sensors show a partial recovery, others do not recover at all at ambient conditions.

When applying sufficient thermal energy to the polymer, contaminants can effectively be outgassed as demonstrated in **Figure 5**. For direct comparison, two identically contaminated SHT4x sensors are compared to each other in a controlled environment. One of the SHT4x sensors got its on-chip heater activated with 110 mW for 80 min, yielding an elevated temperature of ~110 °C, whereas the other SHT4x was not heated. After the heating period, the humidity signal of the heated sensor was recovered within specifications, see **Figure 5**, transient curve after $t = 100$ min. Moreover, the sensor fully recovered over the whole relative humidity range, which is not shown here. This demonstrates that (i) chemical contamination can be fully reversed and (ii) decontamination can be strongly accelerated.

Details on how to operate the heater can be found in the SHT4x datasheet on Sensirion's webpage.

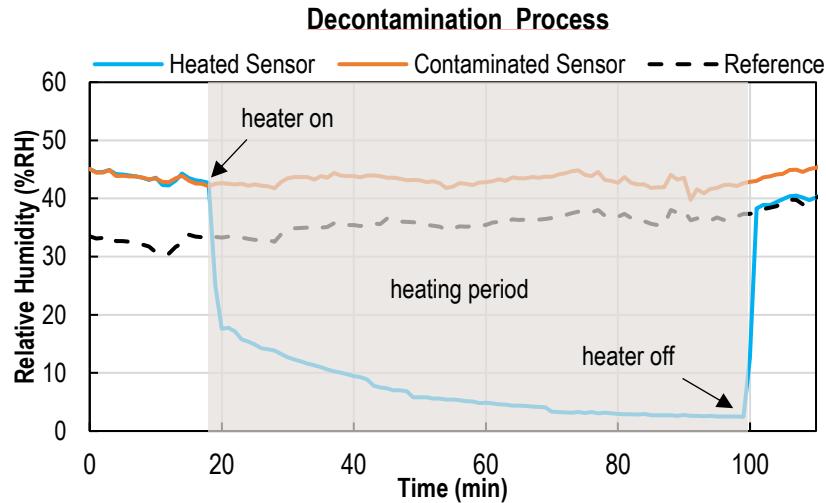


Figure 5: Two contaminated SHT4x sensors are kept at room temperature. On one SHT4x (blue), the on-chip heater is activated for 80 min, yielding an elevated temperature of $\sim 110^\circ\text{C}$. After the heating, the sensor is fully within accuracy specifications, whereas the non-heated SHT4x (orange) displays a residual offset.

4 Limitations and Recommendations for Heat-Assisted Contamination Removal

There are two things to be kept in mind, when using the SHT4x heater. First, sensor accuracy specifications are not valid during the heating period. Second, heater activation requires a sufficiently strong power supply and is therefore not favorable for battery-driven devices.

In order to maximize the overtemperature when using the heater, reduced heat conduction and heat capacity of the mounted sensor are desired. This can be achieved by: (i) not soldering the die pad of the SHT4x, (ii) designing the PCB with a cutout around the sensor (see **Figure 6(b)**) and (iii) reducing the thermal mass of the sensor-PCB compound by using a thinner PCB substrate with low heat capacity. These measures will increase the decontamination yield avoiding excess energy consumption.

For reference, the results shown in **Figure 5** were obtained with a SHT4x on a Flex-PCB of 150 μm thickness. The copper track cross sections are $17.5 \times 200 \mu\text{m}^2$, see **Figure 6(a)**.

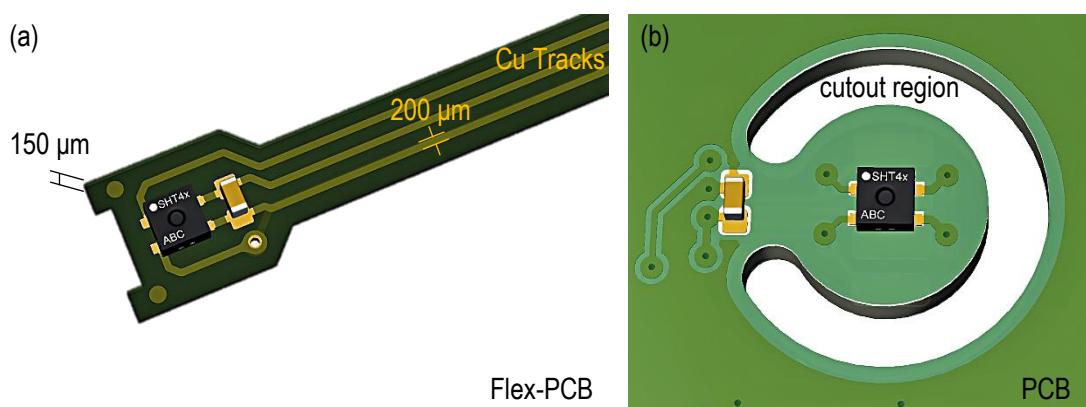


Figure 6: PCB layouts optimized for minimal thermal heat sinks influence. (a) Thin Flex-PCB with 200 μm width copper tracks with isolated sensor on one end. (b) Standard PCB with cutout around the sensor area.

Finally, not all chemical contaminants show the same thermodynamic kinetics in the sensing polymer. Thus, heating power and duration shall be adapted to address some other contaminants than acetone. However, no list of treatable contaminants is specified here.

5 Further Information

For further reading on the SHT4x specifications, communication, and heater details, please consult the SHT4x datasheet provided on the Sensirion download center: <https://sensirion.com/products/downloads/>

6 Revision History

Date	Version	Page(s)	Changes
March 2022	1.0	all	Initial release

7 Bibliography

- [1] Sensirion, "Handling Instructions for Humidity Sensors," 2020. [Online]. Available: www.sensirion.com.

Important Notices

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.

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.

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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.

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