Application Note

How Chemical Contamination Impacts Humidity Sensors

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ABSTRACT

Relative humidity (RH) sensors are susceptible to performance degradation and permanent accuracy shifts caused by chemical contamination. Because these sensors utilize open-cavity packages to allow moisture transmission, they are inherently exposed to undesired solids, liquids, and gases that can alter the dielectric properties of the sensing polymer. This document examines the mechanisms by which various contaminants, categorized as *bulk* (gaseous) or *surface* (solid/liquid)—impact sensor accuracy through changes in polarity, dielectric constants, and ionic conductivity. Furthermore, this application note provides actionable strategies to mitigate these risks, including the analysis of manufacturing chemicals via their material safety datasheets (SDS or MSDS), the use of moisture permeable membrane filters or removable polyimide tapes, and the utilization of integrated heaters to accelerate contaminant diffusion.

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Trademarks

1 Introduction

1.1 Why Chemical Contamination Occurs

Capacitive-based relative humidity (RH) sensor ICs utilize open-cavity packages to allow transmission of environmental moisture into the package. To capture the water vapor in the air, a polymer layer is placed over the sensing electrodes within the cavity to act as a dielectric to the capacitive sensor. Water vapor interacts with the polymer, and alters the dielectric constant. This change in dielectric constant creates a change in capacitance for the sensing electrode beneath the polymer which is then converted internally into a relative humidity output.

Due to the presence of this cavity, RH sensors are not only exposed to moisture but also multiple other undesired chemicals. When additional chemicals are introduced into the sensing polymer, they change the dielectric properties of the polymer and can alter the RH performance of the RH sensor. These unwanted chemicals are referred to as contaminants. The impact on sensor accuracy is variable and is dependent on the type, concentration and exposure period of contamination.

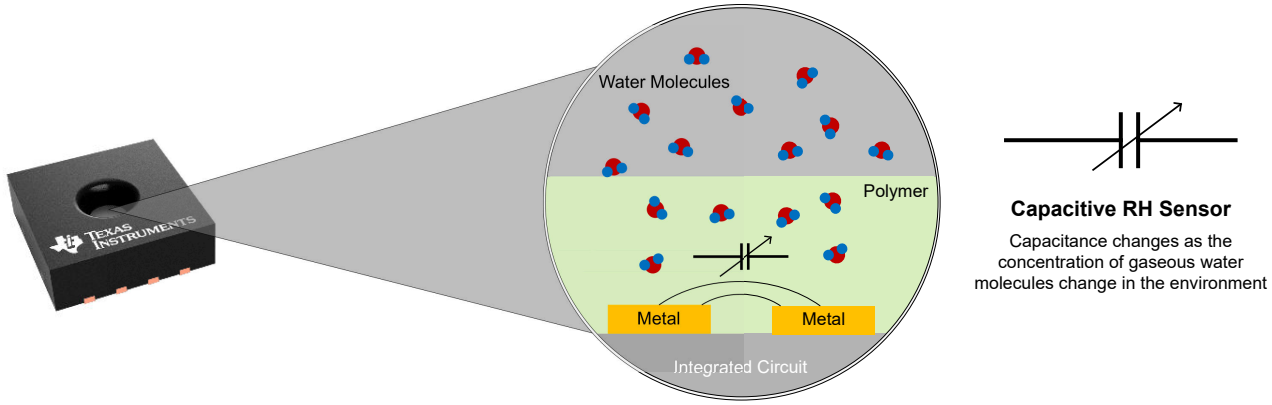

Figure 1-1. Capacitive Humidity Sensor Structure

1.2 Types and Sources of Chemical Contaminants

Figure 1-2 shows the images of a sensor area with visible contamination such as solid or liquid and gaseous contamination. Solid contaminants such as dust particles and smoke can accumulate onto the sensor over a period. Liquid contaminants such as water with ions, saliva, sweat, cleaning flux as well as gaseous contaminants, such as volatile organic compounds, can affect the sensor polymer and hence the RH output. Volatile organic compounds (shortened to VOCs) are organic chemicals, often human-made, that have a high tendency to vaporize into the air, otherwise known as *off-gassing*. These interactions cause shifts in RH accuracy and depending on the level of exposure can cause permanent RH accuracy errors as well.

Chemical contamination can be in the form of any state of matter. Liquids, gases, and solids can cause RH accuracy errors. Table 1-1 shows a non-exhaustive list of potential sources of chemical contamination that can be in different states of matter.

Table 1-1. Contaminant Types and Effects

State of Contaminant	Contaminant Type	Source/Cause	Symptoms	Effect on Sensor
Solid	Cigarette ash	Human Interactions	Negative RH error offset, negative RH gain	Covering sensor surface causes hinderance to transmission of water vapor
	Smoke ash	Indoor/outdoor atmosphere with low ventilation		
	Dust particles	No air flow		
	Salt	Human interactions	Negative RH error at high RH levels	Ions create a conductive path, reducing the capacitance of sensor
Liquid	Water with ions	Corroded water pipes, presence of salt in water		
	Sweat	Human Interactions		
	Saliva	Human Interactions		

Table 1-1. Contaminant Types and Effects (continued)

State of Contaminant	Contaminant Type	Source/Cause	Symptoms	Effect on Sensor
	Solder Flux	PCB wash	Negative gain, positive or negative RH error offset	Depending on polarity, chemical interaction with polymer, and amount of contaminant, will alter the dielectric constant of the polymer by occupying voids in polymer that could potentially store water vapor molecules
Gaseous	Volatile organic compounds (VOCs)	Outgassing from conformal coatings		
		Outgassing from cleaning flux		
		Outgassing from antistatic polyethylene/ LDPE packing materials (sometimes referred to as *pink foam*)		

While knowing the state of matter is helpful for understanding that chemical contamination can occur from a wide variety of sources, to understand the potential impact on RH sensor performance, it is helpful to sort chemical contaminations into two categories: *Bulk* contamination, and *Surface* contamination. Surface contamination refers to solids and liquids, where there is a visible material deposited onto the surface of the sensing polymer. Bulk contamination can be defined as gaseous contamination where the molecules embed into the body of the polymer and are not able to be seen with a microscope looking at the surface of the sensor cavity. While much of the impact on RH performance is determined by the chemistry of the contamination, whether the contamination is surface or bulk also matters. Surface contaminations can often be cleaned off with distilled water or wiping (See section 4.6.4 of How to Debug RH Accuracy Issues in RH Sensors for additional details), but bulk contaminations cannot be externally cleaned. Resolving a bulk contamination requires heat to accelerate the diffusion of the contaminant out of the polymer structure.

#none##none# illustrates multiple different examples of what surface contamination can look like. In images A & B, the surface contamination is solid material deposited on the polymer in different amounts. Image C shows dried rings from liquid contamination, potentially leaving solid contamination behind after the liquid has evaporated.

On #none##none#, the larger green circle shows a view of the entire center cavity zoomed in to show the polymer. The smaller yellow circle is the inner sensor area, where the capacitive sensing electrodes are located. The capacitive electrodes do not cover the whole sensor die or the entire polymer surface. The inner sensor circle is much more sensitive to chemical contaminations than the outer circle area. Figure 2-1, Figure 2-2, Figure 2-3, Figure 2-4, and Figure 2-5 show this inner circle sensor area in a simplified manner and from a cross-sectional view plane, omitting the outer polymer area.

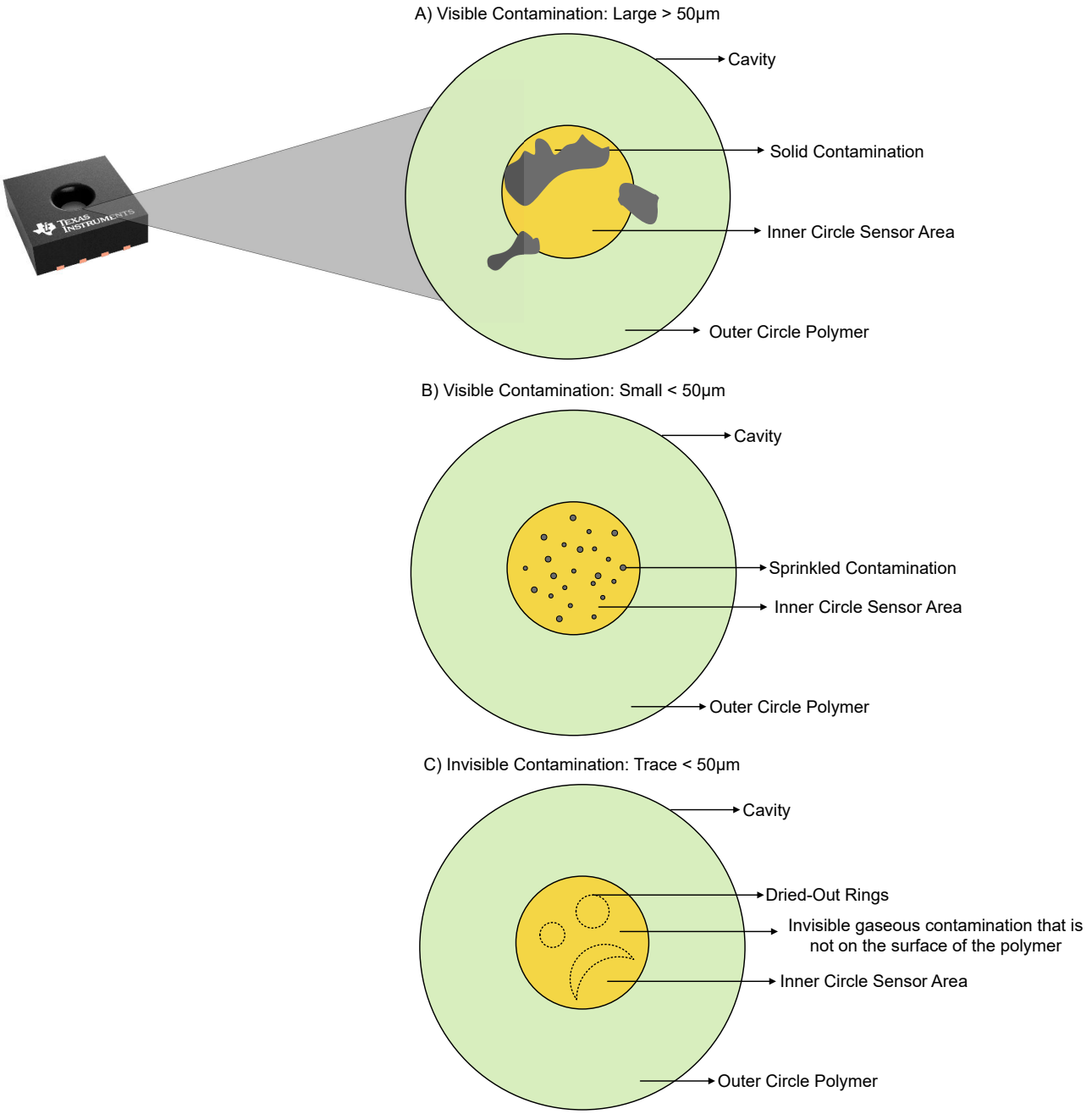

Figure 1-2. Examples of Different Surface Contaminations

2 Detailed Description

Mechanism of contaminant interaction with sensors

The dielectric constant (ε) of a molecule and its polarity are directly proportional to each other. Dielectric constant measures a material's ability to store electrical energy relative to a vacuum. Polarity is the measure of charge separation within a molecule. Higher polarity enables higher charge storage as the molecules align themselves in presence of electric field. Thus, generally higher polar molecules will have higher dielectric constant. Polymers used for capacitive humidity sensors act as dielectric material for the capacitive electrodes. Typically, sensing polymers will have a dielectric constant between 2 and 3. Water vapor primarily interacts with polymer based on its polarity or dielectric constant of 80 at room temperature which varies over temperature. When a water molecule dipole encounters the surface of the polymer, the high polarity of water molecules alters the dielectric constant of the polymer itself. The increasing amount of water vapor increases the overall change in dielectric constant of polymer which is captured by analog signal chain on the IC as capacitance change. The dielectric constants of several common solvents are shown below in Table 2-1:

Table 2-1. Examples of Solvents and their Dielectric Constants

Solvent	Dielectric Constant (ε)
Acetic acid	6.15
Acetone	20.7
Acetonitrile	37.5
Anisole	4.33
Benzene	2.27
Bromobenzene	5.17
Carbon disulfide	2.6
Carbon tetrachloride	2.24
Chlorobenzene	5.62
Chloroform	4.81
Cyclohexane	2.02
Dibutyl ether	3.1
o -Dichlorobenzene	9.93
1,2-Dichloroethane	10.36
Dichloromethane	8.93
Diethylamine	3.6
Diethyl ether	4.33
1,2-Dimethoxyethane	7.2
N,N -Dimethylacetamide	37.8
N,N -Dimethylformamide	36.7
Dimethyl sulfoxide	46.7
1,4-Dioxane	2.25
Ethanol	24.5
Ethyl acetate	6.02
Ethyl benzoate	6.02
Formamide	111
Hexamethylphosphoramide	30
Isopropyl alcohol	17.9
Methanol	32.7
2-Methyl-2-propanol	10.9
Nitrobenzene	34.82
Nitromethane	35.87

Table 2-1. Examples of Solvents and their Dielectric Constants (continued)

Solvent	Dielectric Constant (ε)
Pyridine	12.4
Tetrahydrofuran	7.58
Toluene	2.38
Trichloroethylene	3.4
Triethylamine	2.42
Trifluoroacetic acid	8.55
2,2,2-Trifluoroethanol	8.55
Water	80.1
o -Xylene	2.57

Table 2-1, taken from: https://depts.washington.edu/eooptic/linkfiles/dielectric_chart%5B1%5D.pdf

Consider bulk contaminations due to gas (for instance, VOCs off-gassed from PCB assembly chemicals such as adhesives or paint) or surface contaminations (for example, from a liquid solvent). If the polarity or dielectric constant of the contaminant is large and interacts with hydroxyl surface states of the polymer, it can alter the dielectric constant or overall capacitance output of the polymer. This will be read as change in %RH output of device despite no change in actual moisture level. This contaminant interaction is a combinatorial effect of following parameters:

- **Polarity of contaminants**

  Typically, small carbon chain VOCs such as isopropyl alcohol, acetone, ethanol are more polar than long carbon chain VOCs such as butane. Carbon chain molecule's polarity will typically increase with length, and those with functional groups attached (for example, alcohols or ketones) will even more polar. Whereas cyclic organic compounds such as cyclopentane, Benzene, and Toluene are non-polar. Choosing chemicals with less polarity or non-polarity helps to reduce the shift in overall sensor accuracy. Non-polar solvents will typically have dielectric constant even lower than the polymer and thus have a relatively insignificant impact on the RH accuracy shift.

  Even if a potential chemical contamination is non-polar there can be impacts to the accuracy of the sensor. When the exposure concentration is very high and sustained, the polymer can swell due to how much of that chemical has diffused into it. Often the sheer size of the contaminant molecule will occupy a significant amount of free space in the polymer voids. This will further contribute to swelling of the polymer and alter the dielectric constant just through the sheer amount of contaminating molecules there are. Therefore even if a chemical contaminant is non-polar and hence lower risk of affecting the RH accuracy, exposure should be limited as much as possible to protect the RH sensor's accuracy.
- **Concentration of contaminants compared to RH levels and the diffusion rate.**

  Fickian diffusion is a process where gas particles move from high concentration to low concentration. The diffusion rate of contaminants (liquid or VOC) is a function of its concentration, temperature and affinity towards functional groups of the polymer. In case of the polymer's interaction with moisture or contaminant, it will be a linear function of concentration of moisture/contaminant inside the polymer versus in the ambient at the air-polymer interface. The later stage of this diffusion involves significant reduction in rate of absorption as the material approaches saturation and results in swelling of the polymer.

  Non-polar molecules typically are unable to penetrate the compact polymer chain matrix due to their lack of polarity. Polar molecules will diffuse into the matrix depending on their initial concentration and highly attractive force towards polar molecules of the polymer.

Figure 2-1 below illustrates the Fickian diffusion. Molecules that are more polar will penetrate deeper into the polymer matrix due to their enhanced diffusion rate. This means that their impact on sensor accuracy will be enhanced, and more challenging to be diffused out of the polymer.

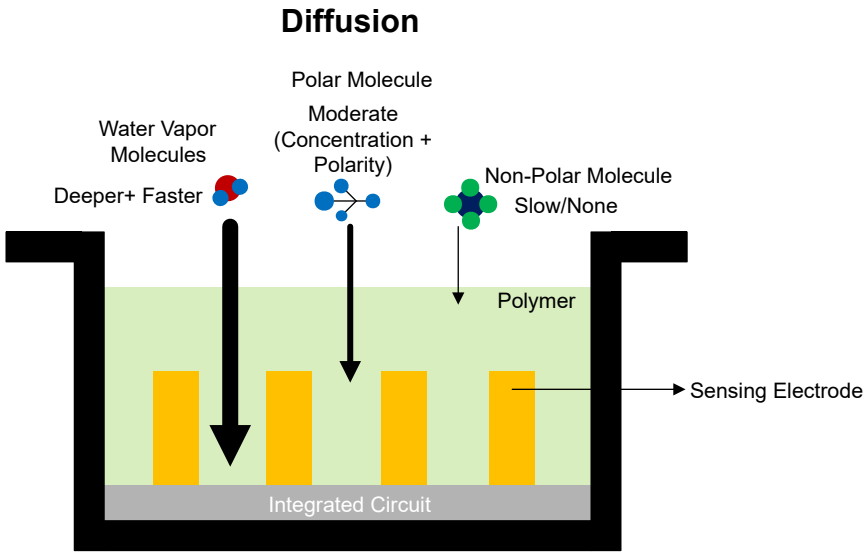

Figure 2-1. Diffusion Properties of Different Levels of Polar Molecules

- **Affinity of contaminants towards the functional groups of the sensing polymer**.

  Polar protic solvents interact with polymer functional groups through hydrogen bonding, often increasing the overall dielectric constant of the polymer. Polar protic solvents contain hydroxyl groups which directly compete with water vapor to occupy the polymer since they bond in the same way. This is the main mechanism of moisture interaction with polymer. Thus, alcohol such as ethanol and isopropyl alcohol (IPA) will always have large impact on RH accuracy. Some polar aprotic solvents such as acetone will interact with the sensing polymer by affecting the overall polarity instead of directly competing with water vapor molecules. These will also result in an increase in the dielectric constant of the polymer.

2.1 Non-Polar Chemical Contamination

Non-polar solvents in low concentrations will have minimal to no interaction with functional groups of the polymer when exposed in limited quantities. Thus, chemicals such as cyclopentane or Toluene will have negligible impact on sensor accuracy. This is shown in Figure 2-2. Non-polar molecules do not penetrate deep into the polymer matrix and have a relatively small impact on RH output. Since the non-polar molecules are still taking the place of water vapor molecules in the polymer voids, they do slightly reduce the RH output.

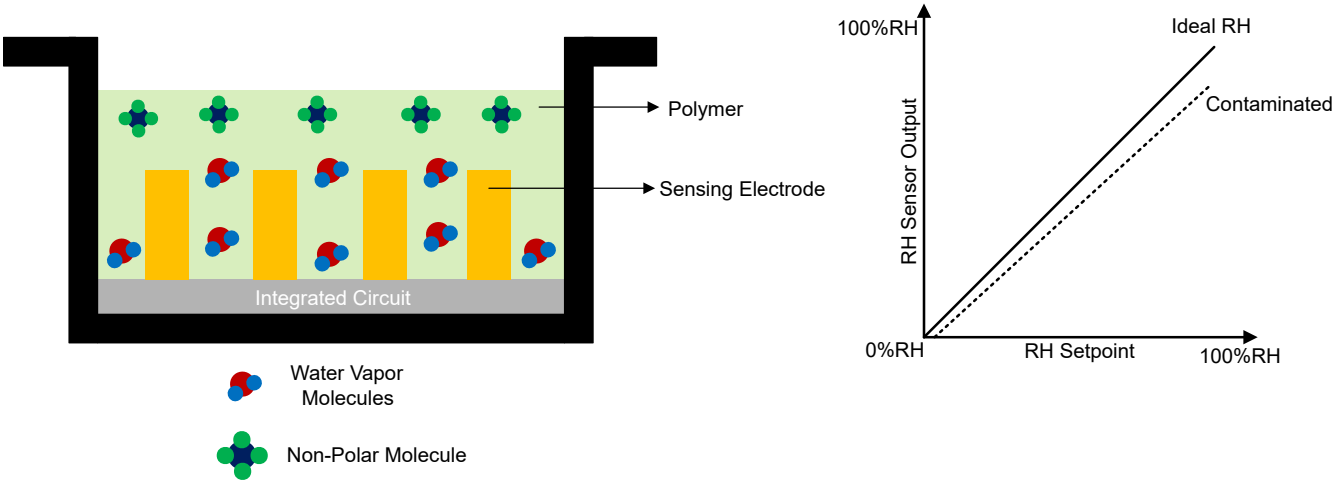

Figure 2-2. Small Shift in RH Accuracy from Non-Polar Contamination

2.2 Polar Chemical Contaminations

In #none#, a more polar molecule is contaminating the sensing polymer. Because the overall dielectric constant is being changed from what just water vapor would do, the RH output changes as well. In this case, negative RH gain and positive RH error shifts can be expected. Water vapor has a very high dielectric constant, as seen in Table 2-1, even compared to other chemical contaminants. This means that when ambient RH is high, the RH sensor output will shift down since less of the highly polar water vapor molecules can penetrate the polymer due to the presence of the contaminant. Conversely, at lower ambient RH levels the RH output is elevated because the polar molecules are increasing the overall dielectric constant of the polymer.

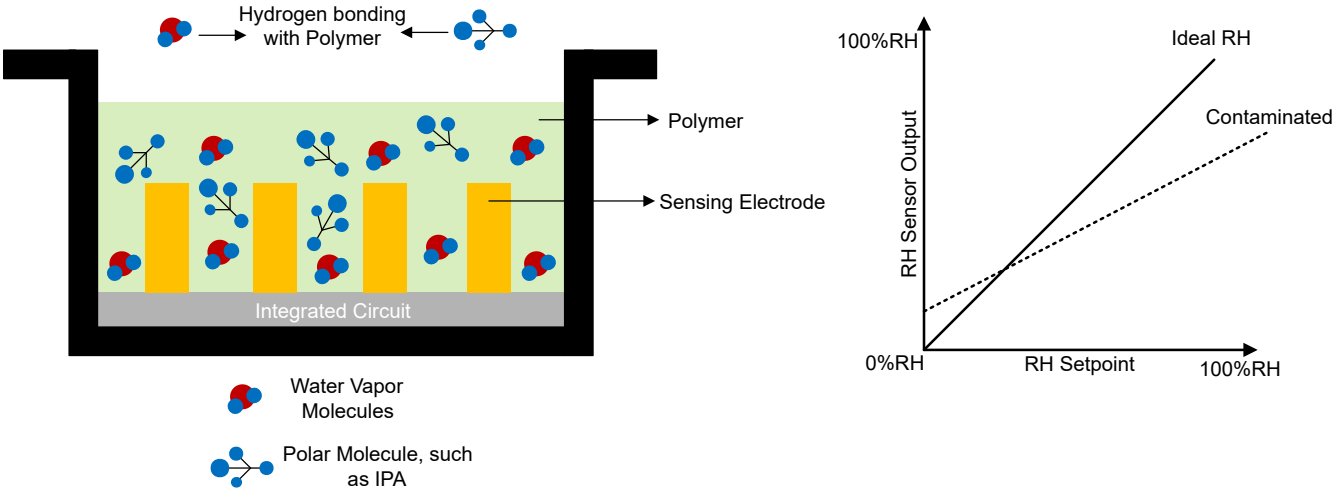

Figure 2-3. Significant Shift in RH Accuracy from Polar Contamination

2.3 Ionic Chemical Contamination

Another kind of chemical contamination is Ionic contamination. Ionic contamination can be identified through a signature RH error profile, where at room temperature sensor RH appears normal at low ambient RH levels but as ambient RH increases the sensor RH error begins to drop precipitously resulting in very large errors, often exceeding -10%RH, at high RH levels (>80%RH). Small, high charge density ions like sodium can impact the local polarity of water molecules causing losses or less change in the dielectric constant of the sensor polymer. At higher RH, there is a lot more conductive ions dissolved paired with a larger amount of moisture being absorbed, which causes more leakage. Because of this effect, the RH output is significantly lower at higher humidity levels causing a negative gain in accuracy.

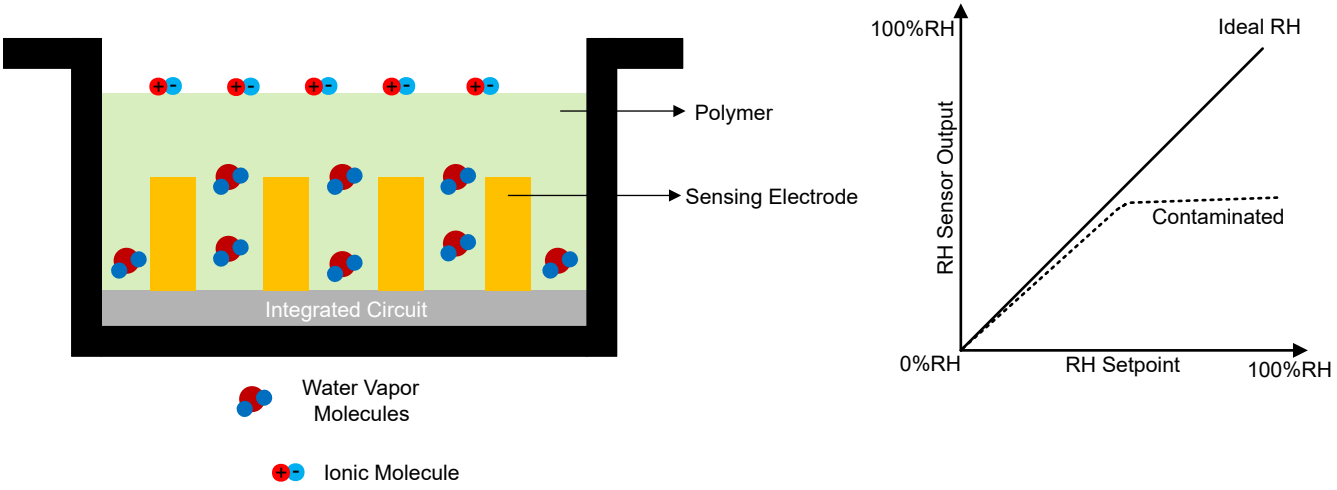

Figure 2-4. Ionic Contamintion Resulting in Significant Shift in RH Accuracy at High Ambient RH

Ionic contamination can occur by using tap water for cleaning or due to the condensation of water molecules containing salts. Saliva and sweat contamination into the cavity shows similar signature shifts as ionic contamination as these human fluids also contain conductive ions from salt. At times, dust accumulation interacting with moisture under high RH conditions can also activate insulating dust into a conductive nature. Figure 2-4 shows the ionic contamination on the surface layer, and not penetrating into the polymer. This is because in almost all cases, ionic contamination exist in nature as liquids or solids that sit on the surface of the polymer.

2.4 Surface Chemical Contamination

Thick accumulated layers of dust, smoke debris, paint and conformal coatings can physically block the diffusion of moisture into the polymer. In such cases, it is typical to see no change in sensor RH output even though ambient RH is changing or a negative RH gain with a negative RH offset. Depending on the amount of blocked sensor area with the solid debris, this negative gain can be drastic. While the illustration in Figure 2-5 shows solid contaminations distributed across the polymer surface, solid contaminations must be in the inner circle of the sensing area (where the electrode sensor mechanism is present) to impact RH accuracy. When the contaminant (in any state of matter) gets onto the polymer, it diffuses down into the polymer. If that diffusing contaminant is not over the inner sensor area, then it will not interact with the electric field and not impact the sensor's capacitance. For gases, this is irrelevant because those evenly distribute over the cavity space. But solid contamination can be localized. If solid contamination is observed but is not located on or adjacent to the inner sensor area, then it is unlikely to impact the RH accuracy.

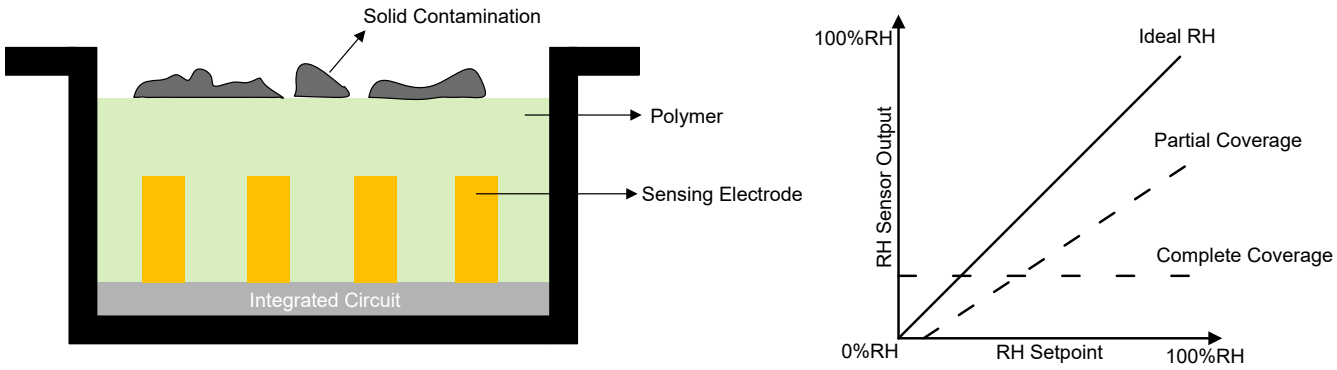

Figure 2-5. Surface Contamination Impact on RH Accuracy

2.5 What Preventative Actions Can Be Taken?

Vigilance and proactive awareness can help reduce the contaminations during manufacturing flow.

1. How to analyze chemicals used in manufacturing process:
   a. List all potential chemicals used in board manufacturing process
   b. Check the MSDS (Material safety datasheet) for these chemicals. Every MSDS has an ingredients section listed. Locate this section in MSDS document.

      Below is an example using a Humiseal epoxy MSDS.

SECTION 3: Composition/information on ingredients

Mixture

General information

Chemical name	%	CAS-No. / EC No.	REACH Registration No.	Index No.	Notes
n-Butyl acetate	80 - < 90	123-86-4 204-658-1	-	607-025-00-1	#
Classification: Flam. Liq. 3;H226, STOT SE 3;H336					
Butanone	10 - < 20	78-93-3 201-159-0	-	606-002-00-3	#
Classification: Flam. Liq. 2;H225, Eye Irrit. 2;H319, STOT SE 3;H336					

Figure 2-6.

ii. Identify the solvents in the table:

SECTION 3: Composition/information on ingredients

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Chemical name	%	CAS-No. / EC No.	REACH Registration No.	Index No.	Notes
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Classification: Flam. Liq. 2;H225, Eye Irrit. 2;H319, STOT SE 3;H336					

Figure 2-7.

c. Check if the solvents are highly polar or almost non-polar
   i. This can be done by comparing either dielectric constant or polarity index value.
   ii. See the following links, look the information up online, or ask the chemical product manufacturer.
      1. https://www.chem.rochester.edu/notvoodoo/pages/reagents.php?page=solvent_polarity
      2. https://macro.lsu.edu/howto/solvents/polarity%20index.htm
      3. https://depts.washington.edu/eooptic/linkfiles/dielectric_chart%5B1%5D.pdf
      4. https://macro.lsu.edu/howto/solvents/Dielectric%20Constant%20.htm

2. If the polarity or dielectric constant of solvent is high then ask the manufacturer for similar products with non-polar or low polarity solvent based alternatives.
3. In this case, n-Butyl Acetate has a dielectric constant of 5.01 and Butanone has a dielectric constant of 18.5. n-Butyl Acetate is not very polar and should be considered low risk to contaminate the RH sensor. However, Butanone has a high dielectric constant, and is considered to be a polar, aprotic molecule. This means the epoxy is a high risk for chemical contamination and should not be used. A new epoxy without a polar molecule like Butanone should be chosen.
4. In addition to the above, analyze board schematics of enclosures to avoid dust/debris.
5. Frequently check on the water quality used for cleaning board. Using water that is not distilled water may contain ions, minerals, or other molecules which could accidentally contaminate the humidity sensor.
6. Check the cavity using visual inspection capabilities, if available.
   a. Below are examples of visible surface contaminations. Note that not all of the surface contaminations are actually within (or very close to) the darker inner sensor area. The surface contaminations outside of the inner sensor area will not impact RH accuracy.
   b. Selecting a humidity sensor with a PTFE filter cover prevents surface contaminations from reaching the sensor cavity.

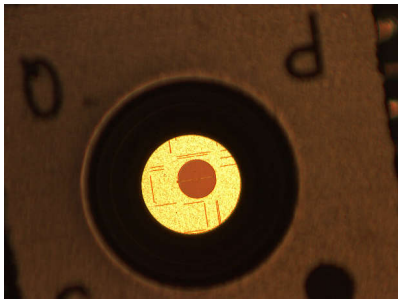


Figure 2-8. Example of HDC3020 with No Surface Contaminations

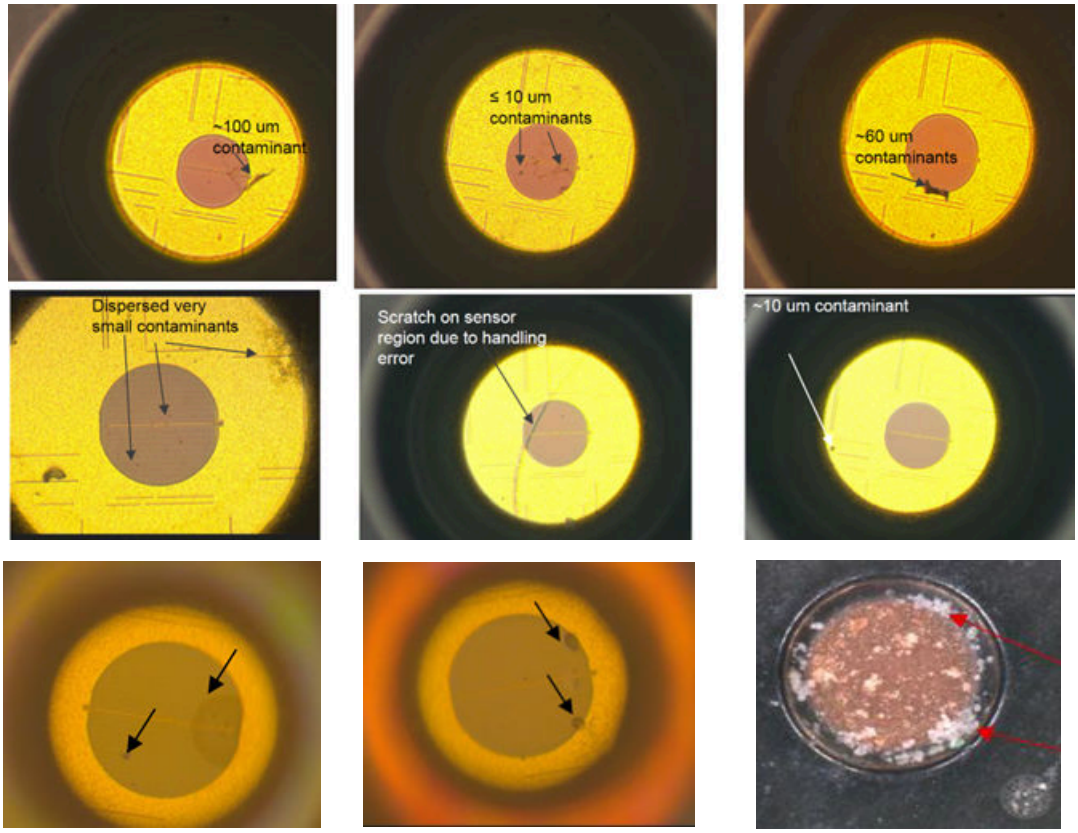


Figure 2-9. Examples of Real Surface Contaminations Visible with Microscope

Even if visual inspection capability is available, it is not always possible to capture the contamination using optical inspection. In certain cases, there are no visible signs of contamination such as interactions with volatile organic compounds. Users must closely review the special handling instructions provided for humidity sensors (provide app note or handling instructions link ref). Proactive analysis of presence of any chemicals in the manufacturing flow and the effect on humidity sensors is the best method to avoid shifts in sensor performance during PCB manufacturing.

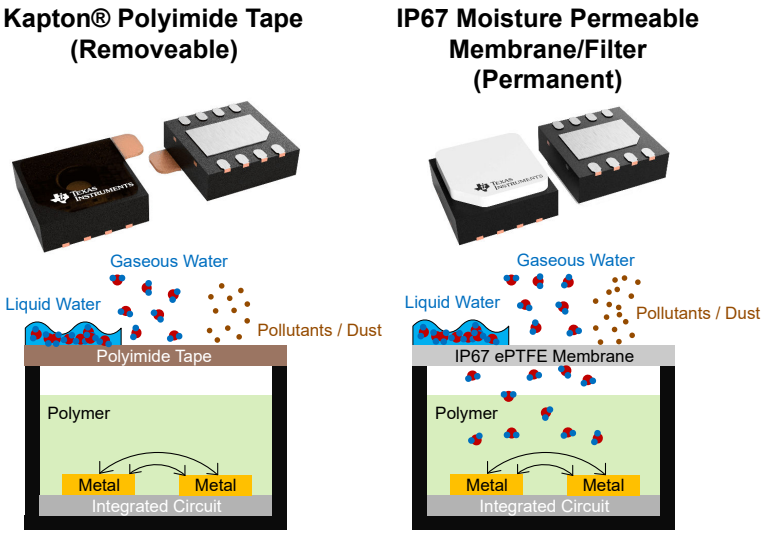
3 Summary

What can be done to mitigate chemical contaminations and what to expect?

In order to maintain the relative humidity sensor accuracy over its lifetime, protective covers can be used to protect against dust, water and chemicals. Protective covers can be external to the PCB, which can protect the sensor and other PCB components from dust/debris/liquids/damage. However TI also offers RH sensors with on-chip protective tape and filter covers that provide additional help in mitigating some of the contamination.

The removable tape on the package is a good option to prevent chemical contaminations during PCB assembly, which is very common source of contaminations. The tape works by allowing the sensor to be covered with coatings/washes/potting materials, then once all the assembly and any curing is done, the tape is peeled off via its side tab. This results in an exposed RH sensor cavity that has not been exposed to any of the potential pollutants in the assembly process.

The permanent IP67 filter is best for when liquid or solid chemical contaminations are considered a risk. The filter should not be removed, and it protects against debris, smoke, dust, condensation, and water submergence. The IP67 must allow water vapor through to sense RH, so gaseous chemicals like VOCs is not be kept out by the filter.



Heating the humidity sensor to a high temperature for a long period of time (to bake it) can remove the drift from contaminants or extreme conditions. When chemical contaminations have been identified during internal testing after assembly, then external baking can work. However, external baking is usually not practical once the sensor is in use. TI humidity sensors have an integrated heater that can be used to heat the RH sensors to accelerate the diffusion of chemical contaminants out of the polymer. The exact duration and power level of the heat to effectively dissipate the contamination will depend on the chemical, its concentration, and the amount of contamination. Baking the RH sensor, whether done through the internal heater or an external oven, is effective for removing bulk contaminations. However, baking cannot typically resolve surface contaminations by any means other than liquid evaporation. Solid surface contaminations usually cannot be removed with a bake (from an oven or the integrated heater), so they must be washed off with distilled water. For more detail on how the use integrated heater, see Using an Integrated Heater to Recover RH Accuracy from High-Humidity Exposure.

The best way to mitigate the impact of chemical contaminations on humidity sensors is prevention. When doing PCB assembly, whether done directly by the user or by a third-party vendor, seek to understand what chemicals are used in the assembly process and evaluate their potential impact on the RH accuracy by looking at their MSDS documentation. For chemicals that are identified to be risky, substitute chemicals that are less risky based on their MSDS. For example, instead of using a chemical PCB wash, either use a no-clean flux so no wash is necessary or wash with distilled water so there is no addition risk of VOC or surface contamination. Make sure that the RH sensor is the last component to be assembled onto the PCB so that there are fewer chemicals and assembly steps it is exposed to.

4 References

1. Texas Instruments, *HDC1080 Low Power, High Accuracy Digital Humidity Sensor with Temperature Sensor*, datasheet.
2. Texas Instruments, *HDC2080 Low-Power Humidity and Temperature Digital Sensor*, datasheet.
3. Texas Instruments, *HDC2010 Low-Power Humidity and Temperature Digital Sensors*, datasheet.
4. Texas Instruments, *HDC302x 0.5%RH Digital Relative Humidity Sensor, 0.19%RH/yr Long Term Drift, 4s Response, Low-Power, Offset Error Correction, 0.1°C Temperature Sensor*, datasheet.
5. Texas Instruments, *HDC302x-Q1 Automotive 0.5%RH Digital Relative Humidity Sensor, 0.19%RH/yr LTD, 4s Response, Offset Error Correction, 0.1°C Temperature Sensor*, datasheet.
6. Texas Instruments, *HDC3120 High-Accuracy (1%RH, 0.2°C) Analog Humidity and Temperature Sensor, With Low Long-Term Drift (0.19%RH/yr), and 4s RH% Response*, datasheet.
7. Texas Instruments, *HDC3120-Q1 High-Accuracy (1%RH, 0.2°C) Analog Humidity and Temperature Sensor, With Low Long-Term Drift (0.19%RH/yr), and 4s RH% Response*, datasheet.
8. Texas Instruments, *HDC2x Silicon*, user's guide.
9. Texas Instruments, *HDC3x Silicon*, user's guide.
10. Texas Instruments, *How to Debug RH Accuracy Issues in RH Sensors*, application note.
11. Texas Instruments, *Using an Integrated Heater to Recover RH Accuracy from High-Humidity Exposure*, application note.
12. Texas Instruments, *TI Humidity Sensors: Programming & Integration Guide*, application note.
13. Texas Instruments, *Humidity Sensor Comparison Guide*, product overview.
14. Not Voodoo XX, https://www.chem.rochester.edu/notvoodoo/pages/reagents.php?page=solvent_polarity, webpage.
15. Lousiana State University, *Polarity Index*, webpage.
16. Washington University, *Dielectric Constant of Common Solvents*, webpage.
17. Lousiana State University, *Dielectric Constant*, webpage.

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