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Evaluation of a MEMS-based Absolute Humidity Sensor using Thermal Conductivity

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Summary: Thermal conductivity sensors, which are often used to measure gases such as hydrogen, are influenced by humidity changes. While this usually leads to challenges in compensating these effects, we are investigating the potential of thermal conductivity sensors as humidity sensors. Using a gas mixing model from Melling, it is shown that thermal conductivity sensors have limitations at low to medium humidity levels. In environments with high temperatures and humidity, where common relative humidity sensors often have problems, thermal conductivity sensors offer a significant potential for accurate measurements.

Keywords: thermal conductivity, absolute humidity, MEMS, humidity sensor

Background

In our previous work, we investigated the impact of humidity on a thermal conductivity sensor for the detection of hydrogen [1, 2]. This measurement principle is particularly well-suited for hydrogen detection due to its high thermal conductivity. Humidity usually poses challenges for thermal conductivity gas sensors as it affects the resulting thermal conductivity of the gas mixture. Nevertheless, this sensitivity to humidity can also be utilized.

Okcan and Akin e.g. demonstrated the use of a thermal conductivity sensor to measure the relative humidity at $20°C$, $30°C$ and $40°C$. They observed a nearly linear response of the sensor [3]. Essing et al. used the thermal conductivity changes caused by humidity to compensate for humidity influences in their photoacoustic sensor [4]. Kimura introduces a method to measure absolute humidity changes using a single micro-air-bridge heater while compensating for the ambient temperature [5].

In this short paper, we want to evaluate whether a MEMS-based thermal conductivity sensor such as the one used in prior investigations can also be used as a low-cost absolute humidity sensor for specific applications.

Materials and Methods

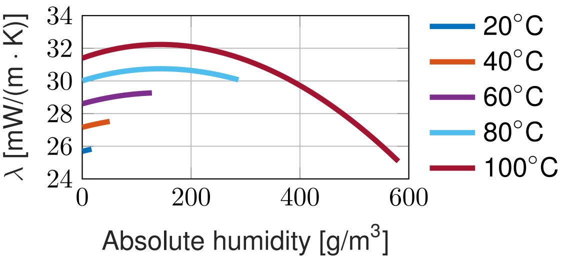

Fig. 1: Thermal conductivity of humid air across absolute humidity according to Melling et al. [6]

In this study, we employ an adapted model provided by Melling et al. [6] which is based on a gas mixing equation introduced by Mason and Saxena [7]. We have previously validated this model using our thermal conductivity sensor and two other commercially available thermal conductivity sensors, demonstrating that it can describe the behavior of thermal conductivity sensors towards absolute humidity [2]. The thermal conductivity as a function of absolute humidity, as predicted by Melling's model, is illustrated in figure 1. The graph displays the thermal conductivity of a gas mixture containing air and water vapor in the range of 0 to 100% relative humidity at the respective temperature.

Results

A limiting factor of thermal conductivity humidity sensors is notable in figure 1. The parabolic shape of the function indicates that a single thermal conductivity value can correspond to two distinct humidity values. To avoid ambiguity, the measurement environment must be constrained to a specific range of humidity.

We can estimate the performance of our thermal conductivity sensor towards sensing humidity by determining the humidity resolution of the sensor using the derivative of thermal conductivity with respect to the absolute humidity and the noise level of the sensor.

$$resolution = \frac{3 \cdot \lambda_{rms}}{\frac{d\lambda}{dAH}} \qquad (1)$$

Figure 2 illustrates the derivative of the thermal conductivity with respect to absolute humidity

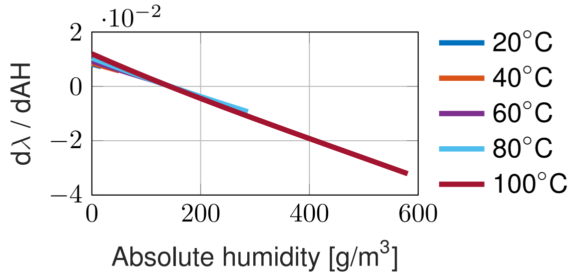

Fig. 2: Derivative of the thermal conductivity with respect to the absolute humidity (AH) according to simulation over the absolute humidity range.

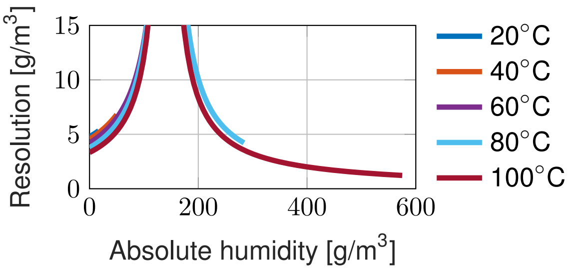

Fig. 3: Resolution according to simulation over the absolute humidity range assuming a rms noise of $0.013\ mW/(m \cdot K)$.

(AH). It shows that the sensitivity of the sensor varies substantially across the evaluated range. The highest sensitivity can be reached at higher temperatures. At the peak point of the humidity dependence, the sensitivity has a zero crossing. Assuming a root mean square (rms) noise λ_{rms} of approximately $0.013\ mW/(m \cdot K)$, we can estimate the resolution using equation 1. The resulting resolution is displayed in figure 3, demonstrating that it is influenced by both temperature and humidity level. As expected, the resolution improves at higher temperatures. Between 100 to $200\ g/m^3$, the resolution undergoes a significant increase due to the zero crossing, after which it decreases with increasing humidity and approaches zero.

Tab. 1: Estimated resolution of a humidity sensor based on thermal conductivity assuming a rms noise level of $0.013 mW/(m \cdot K)$*. The resolution is given in %RH dependent on the relative humidity level and the temperature.*

RH [%]	20°C	40°C	60°C	80°C	100°C
0	28.0	9.0	3.3	1.3	0.6
20	28.6	9.7	4.0	2.3	3.5
40	29.2	10.5	5.1	7.1	0.9
60	29.9	11.3	7.1	6.8	0.4
80	30.5	12.4	11.1	2.3	0.3
100	31.2	13.5	23.9	1.5	0.2

To allow a comparison with standard relative humidity sensors, we calculated the estimated resolution as a function of relative humidity level and temperature, expressed in %RH (see table 1). The results indicate that a thermal conductivity sensor is outperformed by standard relative humidity sensors below $100^\circ C$. However, at higher temperatures and high humidities, relative humidity sensors often experience limitations whereas the estimated resolution for a thermal conductivity sensor significantly improves. This suggests that a thermal conductivity sensor has significant potential for applications requiring the measurement of small changes in humidity at high temperatures and absolute humidities. Furthermore, a physical measurement principle like thermal conductivity, leads to a very stable sensor and is less prone to aging and drifting. Averaging and data processing can further increase the performance of the sensor.

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