# IN-HOUSE DEVELOPED TRACE HUMIDITY SENSORS FOR MEASUREMENT OF MARTIAN ATMOSPHERIC HUMIDITY.

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**Introduction:** The accurate quantification of atmospheric humidity on Mars is of vital importance in understanding the Martian climate and in the search for life on Mars. Relative humidity (r.h.) sensors currently deployed on the Martian surface are able to accurately measure down to a few % r.h. [1,2]. Typically this enables measurement of absolute water content of the atmosphere at cooler temperatures, however makes it challenging during the daytime or in warmer or drier regions. To build a full picture of the atmospheric water distribution and variability it is therefore necessary to incorporate trace humidity sensors, working at low relative humidity, into Martian landers or rovers. A trace humidity sensor, including a patented coating [3], has been developed at PASLAB in the Planetary Laboratories group at the DLR, Berlin. The sensor exhibits excellent accuracy at low humidity levels (range 0.3 to 300ppm$_V$) [5] and reasonable reaction times. Tests are underway to fully explore the potential of the sensors under Martian atmospheric conditions. In this contribution we will show the first results with $CO_2$.

**Coulometric humidity sensors:** Coulometric humidity sensors are used in a variety of industries to monitor trace humidity levels. At its most basic, the sensor consists of two spatially separated electrodes located on a substrate onto which the hydrophilic $P_2O_5$ is applied. $P_2O_5$ absorbs water from the surrounding atmosphere creating phosphoric acid and when an electrical potential difference >2V is applied between the two electrodes an electrolysis reaction occurs, resulting in a current between the electrodes proportional to the humidity level in the surrounding gas. The reaction can be summarized as:

$$P_2O_5 + H_2O \rightarrow 2HPO_3$$

$$2HPO_3 \rightarrow H_2 + \frac{1}{2}O_2 + P_2O_5$$

This results in production of molecular hydrogen at the cathode and oxygen at the anode. This basic functioning principle has been optimized, leading to the sensor design shown in **Error! Reference source not found.**.

The sensors are created using thick film printing technology resulting in two interlocking comb-shaped platinum electrodes separated by a glass barrier. The sensors are driven with 35V alternating potential with a period of 20s, which has been found to optimize the longevity of the sensors by distributing the corrosion of the electrodes evenly over the entire sensor.

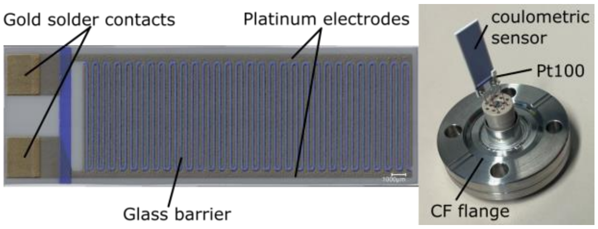

*Figure 1. Left: Coulometric sensor developed at the DLR. Right: Coulometric sensor built into a measurement cell CF-25 flange with a Pt100 temperature sensor.*

If the sensor is active over a sufficient time period in a closed gas volume the water content can be determined using Faraday’s law, since the total charge collected at the electrodes is proportional to the number of water molecules. In reality, and when the sensors are exposed to large body of gas or the atmosphere, the water content can no longer be related in an analytical way to the current due to incomplete absorption into the $P_2O_5$ coating. In this case a calibration is necessary under conditions similar to those experienced at deployment.

**Experimental setup**: In order to test the sensors under Martian conditions the unique test facilities of PASLAB have been utilized. The facility is represented schematically for coulometric sensor research in Figure 2. This setup allows simultaneous measurements of 3 sensors housed in separate measurement cells with separate gas in and outlets. The measurement cells are built using CF vacuum components and welded fittings to reduce the influence of water vapor entering the measuring systems from the laboratory. In addition, the measurement cell walls were plasma polished to reduce contamination and water storage, thus reducing the time

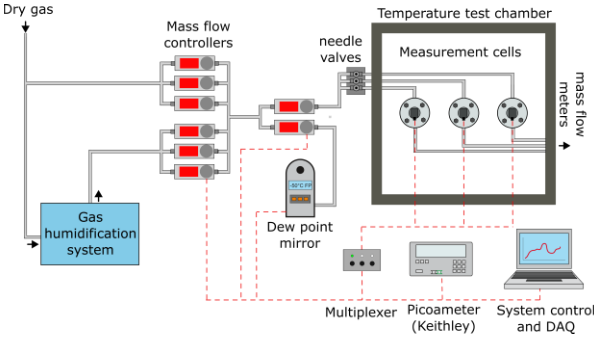

*Figure 2. Experimental setup for sensor research and calibration.*

needed to reach stable humidity conditions to a minimum. The cells are housed in an environmental chamber capable of cooling down to -70 °C. The humidity in the cells is generated using a precision gas mixing system comprising mass flow controllers (Bronkhorst ElFlow-Select), with different calibrated flow ranges, used to mix together dry gas with gas saturated with water vapor at a set temperature and pressure. Since the mass flow controllers are calibrated for $CO_2$, the humidity can be reliably set using the gas mixing system. As a control, a dew point mirror (MBW 373) was used to take reference humidity measurements.

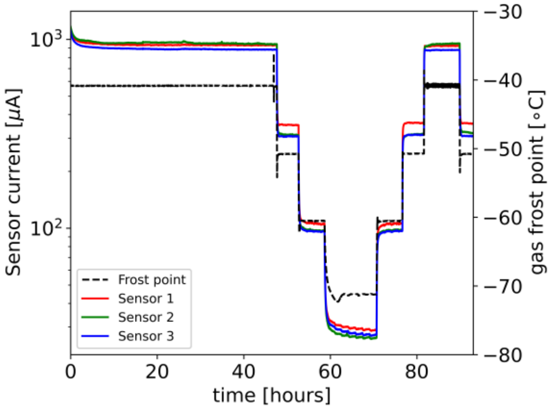

*Figure 3. Current signals from 3 coulometric humidity sensors as a function of time at different humidity points. The frost point reference was measured using a dew point mirror.*

The coulometric sensors were soldered into the connectors of the DN25 CF flanges along with a Pt100 sensor to log the local temperature in each cell (right hand image of Figure 1). The sensors were coated with a patented gel containing $P_2O_5$ [4] and were driven with a square-wave alternating potential of ±35 V, with a period of 20s. The current of each sensor was measured consecutively using a multiplexer in conjunction with a calibrated picoammeter (Kiethley 6485) and the current values at the end of each half-period were extracted by a DAQ and Labview software to reduce signal fluctuation. The lowest humidity point measured in the experimental runs was -70°C FP since the reference measurement was taken with a dew point mirror and is limited by the freezing point of $CO_2$. The flow rate through each measuring cell was set to 20 L/h.

So far tests have been limited to atmospheric pressure, however future tests are planned under full Martian atmospheric conditions, at 6-8 mbar.

**First experimental results:** A typical experimental run is shown in Figure 3 for three simultaneously measured coulometric sensors, along with the reference humidity measurement from the dew point mirror. The sensors were exposed to an initial conditioning at -40°C FP for 48 hours, after which subsequent humidity steps were run down to -70°C FP.

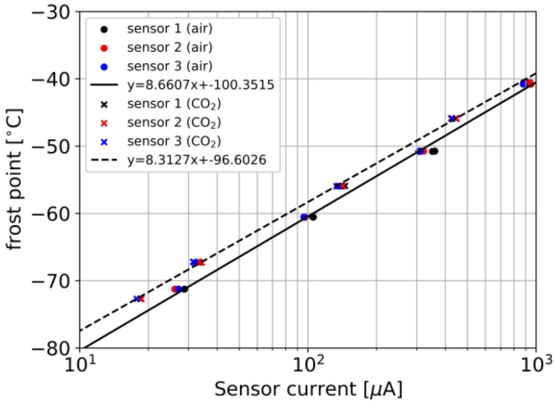

*Figure 4. Calibration curves for the same 3 Coulometric sensors with air and with $CO_2$.*

Figure 4 shows the calibration curves of the 3 sensors at a temperature of +20°C in air and in $CO_2$. The atmospheric water concentration has an exponential relationship with the frost point temperature, resulting in a linear relationship between the frost point and the sensor current on a semi-log plot.

**Summary and outlook:** The coulometric sensors have thus far demonstrated the capability of measuring humidity accurately and reliably in the temperature range -20°C to 20°C at atmospheric pressure in both air and $CO_2$. At lower temperatures it has been observed that the sensors require longer to reach equilibrium, which is expected due to the lower kinetic energy of the electrolyte species. Measurements at T<-20°C are planned, however the intended deployment temperature range is approximately in the region T>-20°C, where currently deployed relative humidity sensors struggle to deliver accurate results. In addition, experiments at Martian atmospheric pressures are planned.

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**References:** [1] Hieta, M. et al. (2023) *EGUsphere*, 1823. [2] Hieta, M. et al. (2022) *Planetary and Space Science, 223*, 105590. [3] Lorek A. et al. (2010) *Proceedings "Aquametry 2010"*, Weimar, 289–296, [4] A. Koncz et al., Coulometrischer Feuchtesensor und entsprechendes Verfahren Patent EP2264445 B1 (2017) [5] Tiebe, C. et al. (2018) *tm - Technisches Messen*, vol. 85, no. 12, pp. 746-753