The precise temperature control of ball SAW sensors for trace moisture measurement at ppb level of concentration

Yusuke Tsukahara, Kazushi Yamanaka, Nobuo Takeda, Shingo Akao, Toru Oizumi, Hideyuki Fukushi, Toshihiro Tsuji

Ball Wave Inc.
The ball SAW sensor

- What is the ball SAW sensor?
- How does it measure the trace moisture?
- We had a difficulty caused by temperature variation.
- How did we solve it?
- Our detection limit is about 1ppbV trace moisture in N₂ gas.
- We detect the trace moisture in hydrocarbon gases with a same calibration curve.
- We detect a-few-seconds spikes of trace moisture.
What is the ball SAW sensor?

SAW goes around and around and around the sphere.
What is the ball SAW sensor?

Amorphous silica film stiffens when it absorbs water molecules.

Quartz crystal
1~3mm in diameter.

Amorphous silica sphere
Film

Water molecules

Interdigital Transducer

Long propagation
⇒ High sensitivity

Amorphous silica film

Time

Wet
Dry

Time of 1 turn
Time of 100 turns
How does it measure the trace moisture?
How does it measure the trace moisture?

We measure
(1) the decay rate and
(2) delay-time of pulses.
Difficulty caused by temperature variation.

- We have to measure the ppm level of change in the delay-time of pulses.

- But the delay-time strongly depends on temperature.

- We need to compensate it for the trace moisture detection at ppbV level.
How did we solve it?

We use two frequencies to compensate for the temperature variation.
How did we solve it?

Relative delay time changes at frequencies $f_1$ and $f_2$, are given by

$$t_1 = B(T) f_1 G(w) + A_1(T \ T_{REF})$$
$$t_2 = B(T) f_2 G(w) + A_2(T \ T_{REF})$$

where $w$ and $T$ are moisture concentration and temperature, respectively.

From these equations, we obtain

$$t_w = t_2 \ C$$
$$t_1 = \left( f_2 / f_1 \right) B(T) G(w)$$
$$t_T = A_1(T \ T_{REF}) = \left( f_2 / f_1 \right) t_1 \ t_2$$
$$t_T = A_2(T \ T_{REF}) \ C$$

where $\left( f_2 / f_1 \right) B(T) = a \exp\left[- k_B(T + 273) \right]$ and $C = A_2 / A_1$.

Falcon Trace (code name)

We implemented the method in a prototype.
Our calibration curves for high end and low end

Decay rate due to moisture dB

Delay time ratio of two frequencies
Our detection limit is about 1 ppbV.

Trace moisture measurement in the nitrogen gas.
Trace moisture in hydrocarbon gases.

- It works in hydrocarbon gases with the same calibration curve.
Trace moisture in hydrocarbon gases.

**H$_2$O Vapor Generation** Case 1: Bubbler Method

- **MFC**
  - 0.1 L/min
  - Dry Gas line

- **MFC**
  - 0.07 to 0.998 L/min

- **MFC**
  - 0.002 to 0.03 L/min

- **Bubbler**
  - 1 L/min
  - 0 °C
  - Saturated vapor pressure @0 °C = 611 Pa

- **Wet Gas line**
  - 40 to 2000 nmol·mol$^{-1}$ H$_2$O
  - ~3 m

- **Rotary Valve**
  - ~0.3 m

- **Ball SAW**

- **Exhaust**

---

**Gas Codings**

- N$_2$
- H$_2$
- CH$_4$
- C$_2$H$_6$
- ...
Trace moisture in hydrocarbon gases.

Transient Characteristics @ 1ppm H₂O Injection
Trace moisture in hydrocarbon gases.

H$_2$O Vapor Generation  Case 2: Diffusion Tube Method
A few seconds spikes in the trace moisture.

• Injected dry N\textsubscript{2} gas and 10ppmv wet N\textsubscript{2} gas alternatively in 5 seconds into the sensor cell.
A-few-seconds spikes in the trace moisture.

Background is not an artifact but is due to the adsorption of moisture on the inner surface of piping.

-65°C FP

-90°C FP
A-few-seconds spikes in the trace moisture.

The ball SAW sensor works with 0 flow rate.
A-few-seconds spikes in the trace moisture.

We can monitor a leakage in a moment.
Thank you for listening.

• We offer a unique solution for the trace moisture measurement with versatile capabilities.

• A prototype for commercial model is available now for early access.