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Simultaneous measurement of gas concentration and temperature by the ball SAW sensor

ボール SAW センサによる ガス濃度と温度の同時測定法

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1. Introduction

Since the sensitivity of a piezoelectric gas sensor depends on the temperature, measured gas concentration is disturbed when the temperature is largely changed. However, it is not easy to measure the sensor temperature, when it is not possible to insert a thermometer into the sensor cell. We have developed the ball surface acoustic wave (SAW) sensor [1] and applied it to trace moisture sensor [2,3], but had the same problem. To solve this problem, we developed a method to simultaneously measure the temperature and gas concentration, using a ball SAW sensor operated at two frequencies [4].

2. Measurement principle

Typical ball SAW sensor cell is shown in **Fig.1** The gas flow rate v is typically 1.0 to 0.1 mL/min. The ball temperature is controlled using a Peltier element and a thermister inserted into the Peltier holder. Due to the need to prevent leakage of the cell, it is not posssible to insert a thermometer into the cell.

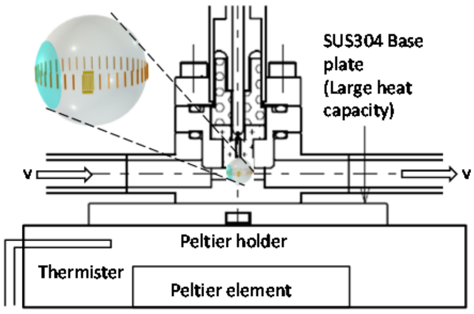


Fig. 1 Cell of ball SAW trace moisture sensor

Relative delay time change (DTC) $\Delta t_1 = \Delta\tau_1/\tau_1$ at frequency f_1 and $\Delta t_2 = \Delta\tau_2/\tau_2$ at frequency f_2, are given by

$$\Delta t_1 = B(T) f_1 G(w) + A_1(T - T_{\mathrm{REF}}) \qquad (1)$$

$$\Delta t_2 = B(T) f_2 G(w) + A_2(T - T_{\mathrm{REF}}) \qquad (2)$$

where $B(T)$ is the sensitivity factor, w is gas concentration, $G(w)$ is a function of w. T is the sensor temperature, T_{REF} is the reference temperature, and A_1, A_2 are temperature coefficients at frequencies f_1 and f_2.

From eqs. (1) and (2), we obtain DTC due to gas concentration,

$$\Delta t_W = \Delta t_2 - C\Delta t_1 = (f_2 - Cf_1)B(T)G(w) \qquad (3)$$

and DTC due to temperature (temperature term)

$$\Delta t_T = A_1(T - T_{\mathrm{REF}}) = \frac{(f_2/f_1)\Delta t_1 - \Delta t_2}{(f_2/f_1) - C} \qquad (4)$$

where $C = A_2/A_1$ is temperature coefficient ratio (TCR). The ball temperature T and gas concentration w are given by eqs. (4) and (3), respectively.

3. Calibration of temperature

Using a sol-gel silica film trace moisture sensor[3] with $f_2 = 3f_1$ [4], TCR was determined as C =0.9875 by a least square fitting of Δt_2 against Δt_1 . The temperature term Δt_T was plotted in **Fig.2**. as a function of the ball temperature T by changing the setting of the Peltier element. Here the ball temperature T was assumed to be identical to the Peltier holder temperature T_{th} when the gas flow rate v is zero.The slope was A_1=-24.25 ppm/°C.

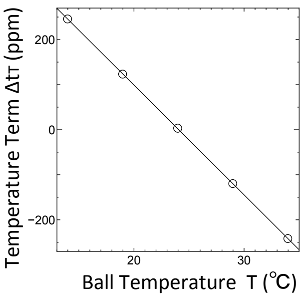
Substituting A_1 and T_{REF} = 24.06 °C into eq.(4), ball temperature is calculated as

$$T = 24.06 - 0.0412\Delta t_T \qquad (5).$$

The error of other temperatures calculated using eq. (5) was evaluated to be less than 0.24 %.

4. Evaluation of heat capacity of sensor cell

To evaluate the effect of heat capacity of the cell, the ball temperature T was compared with the Peltier holder temperature T_{th} measured by the thermistor, as shown in **Fig. 3.** When the setting of Peltier was changed from 34°C to 24°C, T was delayed by 0.5 min from T_{th} and did not reach 24°C even after 3 min. It shows a large heat capacity of the stainless steel base plate.



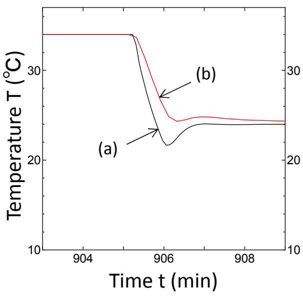


Fig. 2 (Left)Relation between the temperature term Δt_T and the ball temperature.

Fig. 3 (Right) Temperature jump

(a) Peltier holder temperature (b) Ball temperature.

5. Water concentration measurement under varying temperature

The water concentration w in N_2 gas flow was changed by the sequence of 1.3↗234↘1.3↗590↘1.3↗1180↘1.3ppbv, evaluated using the cavity ring down spectroscopy (CRDS) as in [3]. At the same time, the temperature was changed between 24°C and 14 °C using the Peltier element. The DTC Δt_W due to water was measured as shown by the blue curve in **Fig. 4(a)** and **Table I.** The ball temperature T shown by the red curve precisely reproduced the temperature setting, not disturbed by the water concentration change, showing validity of eq. (4).

Using the DTC Δt_W in Table I, right hand side terms of eq.(3) were evaluated as

$$(f_2 - Cf_1)B(T) = a\exp\left[\Delta\varepsilon / k_B(T+273)\right] \qquad (6)$$

with $a = -6.33\times10^{-6}$, $\Delta\varepsilon$ =0.271 (eV), $k_B = 8.617\times10^{-5}$ eV/K (Bolzmann Constant) [5] and

$$G(w) = \sqrt{w} \qquad \text{(e.g.[2,3])} \qquad (7).$$

Substituting eqs. (6) and (7) into eq.(3), we obtain

$$w = (\Delta t_W / a)^2 \exp\left[-2\Delta\varepsilon / k_B(T+273)\right] \qquad (8),$$

where T is given by eq. (5). As shown in **Fig.4(b),** the concentration w almost correctly reproduced the set values in the sequence. Therefore, the concentration measurement under varying temperature was successfully demonstrated.

In **Fig. 5**, narrow time range for the transient from 1.3 to 1180 ppbv is shown. Though the DTC Δt_W (blue curve) in Fig. 5(a) showed a complex behavior due to the change of water concentration and ball temperature (red curve), the water concentration in Fig. 5 (b) almost correctly reproduced the set value. The variation of concentration near temperature jumps is a subject of further study, though it might be due to adsorption/desorption of water from cell and piping.

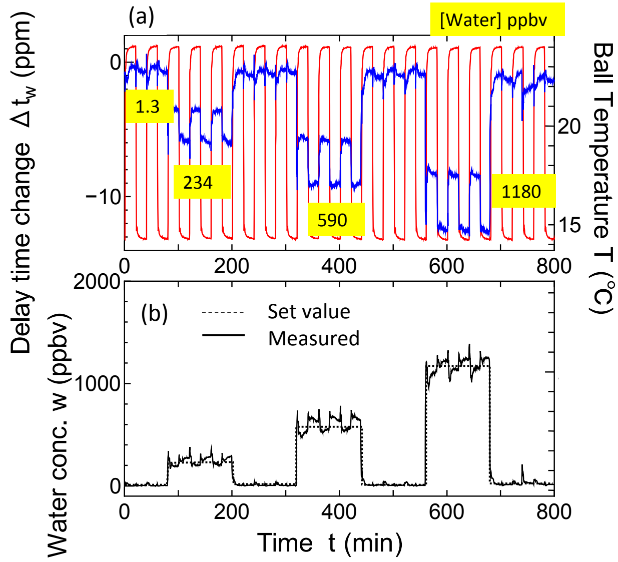


Fig. 4. (a) DTC Δt_W due to water (blue curve; left axis) and ball temperature T (red curve; right axis) (b) Measured water concentration w.

Table I Delay time change Δtw (ppm) at 4 concentration w at two temperatures

w(ppb)	14°C	24°C
1.3	-0.65	-0.36
234	-6.13	-3.33
590	-8.94	-5.94
1180	-12.7	-8.56

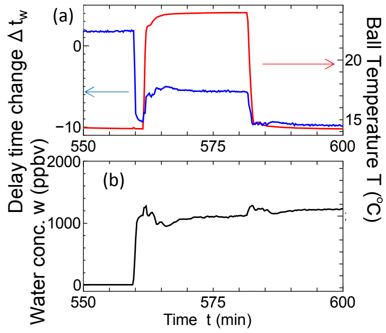


Fig. 5 Part of Fig. 4 for narrow time range.

6. Conclusions

We developed a method to simultaneously measure the temperature and gas concentration with ball SAW sensor. When the temperature had a large jump, the delay time change was significantly disturbed, but the water concentration was almost correctly measured. This method will make ball SAW sensor reliable under varying temperature.

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