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Background gas analysis with leaky attenuation in ball surface acoustic wave trace moisture analyzer

ボール SAW 微量水分計における漏洩減衰を用いたバックグランドガスの分析

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1. Introduction

In trace moisture analyzers (TMA), not only the moisture but also composition of backround gas (BG) is sometimes required. As an example, hydrogen concentration ([H_2]) is required when hydrogen is introduced in NG for transport purpose. In moisture purge of a clean chmber uisng a purge gas, local concentration measurement of the purge gas is ufeful to optimize the purge process.

We have developed the ball SAW TMA with two frequency measurement (TFM) of delay time to compensate temperature variation as well as to measure the temperature. In this work, we extend these works to the TFM of amplitue to measure the composition of BG, as well as to compensate the variation of BG.

2. Principle

In a SAW sensor, burst of two frequency f_1 and f_2 is transmitted and attenuation α_1 and α_2 at each frequency is measured. The attenuations are given by

$$\alpha_1 = a_0 F_1 + a_1(w) F_1^2 + a_2 F_1^y \quad (1)$$

$$\alpha_2 = a_0 F_2 + a_1(w) F_2^2 + a_2 F_2^y \quad (2)$$

where $F_1 = f_1/f_0$, $F_2 = f_2/f_0$, f_0 is a reference frequency.

$$a_0 = \alpha_L l = \frac{f_0 P l}{\rho_S V_S^2}\sqrt{\frac{\gamma M}{RT}} \quad (3)$$

is an attenuation caused by a leakage to the background gas at frequency f_0, where l is the SAW propagation distance, ρ_S, V_S are density and SAW velocity of substrate, P is pressure, R is gas constant, T is temperature, M is molecular weight, γ is ratio of specific heat at constant pressure to specific heat at constant volume. $a_1(w)$ is a viscoelastic loss by moisture, w is moisture concentration, a_2 is a device loss due to scattering at electrodes, etc, and y is a frequency dependence index of the device loss.

A leakage factor is defined as

$$\Delta\alpha_L \equiv \left[(f_2/f_1)^2 \alpha_1 - \alpha_2 \right] / l \quad (4),$$

and from eqs. (1) and (2), it is given by

$$\Delta\alpha_L = \alpha_L (F_1^{-1} F_2^2 - F_2) + (a_2/l)(F_1^{y-2} F_2^2 - F_2^y)$$

(5) Similarly, viscoelastic factor is defined and given by

$$\Delta\alpha_V = \left[\alpha_2 - \left(F_2/F_1 \right) \alpha_1 \right] / l \quad (6)$$

$$= [a_1(w)/l](F_2^2 - F_1 F_2) + (a_2/l)(F_2^y - F_1^{y-1} F_2)$$

In a special case of $F_2 = 3F_1$, $F_1 = 1$,

$$\Delta\alpha_L = 6\alpha_L + (a_2/l)(9 - 3^y) \quad (7)$$

$$\Delta\alpha_V = 6[a_1(w)/l] + (a_2/l)(3^y - 3)$$

Using eqs. (3), (7), a gas parameter is given by

$$G \equiv \sqrt{\gamma M} = B\left[\Delta\alpha_L - (a_2/l)(9 - 3^y) \right] \quad \text{where}$$

$$B = \left(\rho_S V_S^2 \sqrt{RT} \right) / \left(6 f_0 P \right) \quad (8)$$

2. Experiment

In a humid gas with a frost point of -60℃ (10.7 ppmv), the background gas was changed from Air, N_2, Ar to CH_4 as shown in **Fig. 1**. The attenuations α_1, α_2 and the leakage factor $\Delta\alpha_L$ were measured, as plotted in **Fig. 2** and **Fig. 3**. Using the known value of gas parameter G for N_2 and Ar, the coefficient B and the term caused by device loss were calibrated as B =0.1085 and $(a_2/l)(9-3^y)$ =58.53 dB/m. When T and P are changed, these values should be recalibrated using independent measurement of T, P.

Assuming that the first and the fourth background gases in Figs. 2 and 3 are unknown, we measured the gas parameter G^* as 4.43 and 6.36 using eq. (8). We note that they are most close to

4.56 of CH_4 and 6.35 of Air as shown in **Table I**.

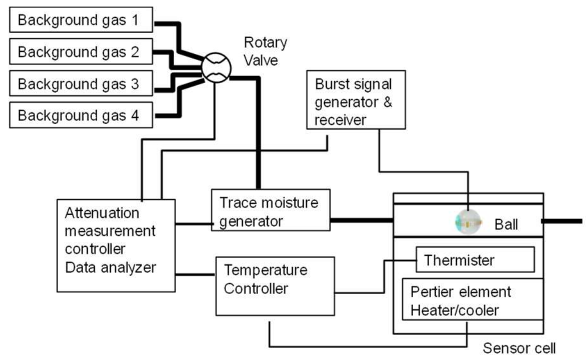

Fig.1 Experimental setup

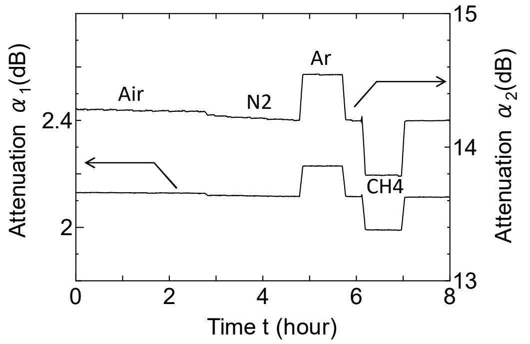

Fig. 2 Attenuation at 80MHz and 240 MHz

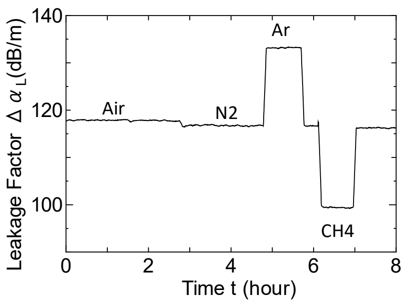

Fig. 3 Variation of leakage factor

Background gas	Molecular weight M	Heat capacity ratio γ	Gas parameter $\sqrt{\gamma M}$
CH4	16	1.30	4.56
N2	28	1.40	6.26
Air	28.8	1.40	6.35
Ar	40	1.67	8.17

Table I. Parameters of background gases

At another frost point of -50℃ (38.8 ppmv), the background gas was changed four times, and the leakage factor was measured. Since they were very close to 6.26, 8.17, 4.56 and 6.35 of N_2, Ar, CH_4 and Air, they are estimated to be these gasses. The measurement error was less than 2.7 %. The measured and true gas parameter for all the experiment is summarized in **Fig. 4**. The agreement between measured and true G is significant.

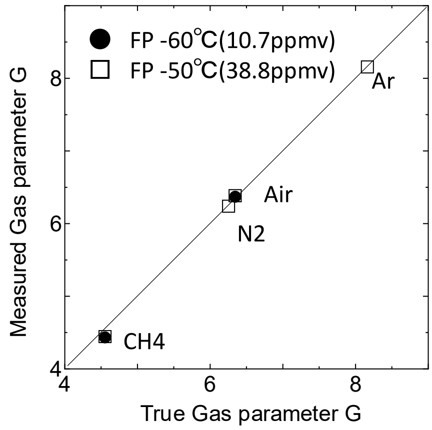

Fig.4 Comparison of measured and true values of Gas parameter.

In a mixed gas, we propose that an average gas parameter is given by

$$\overline{G} = \sqrt{\overline{\gamma}\,\overline{M}} = \sqrt{\left(\overline{C_P}/\overline{C_V}\right)\overline{M}} \tag{9}$$

where $\overline{M}$ is average molecular constant and $\overline{\gamma}$ is average ratio of specific heat at constant pressure C_P to specific heat at constant volume C_V. For mixed gases of He and N_2, the measured gas parameter is plotted against the molar fraction of He in **Fig. 5**. Since they agreed to the calculated value, eq. (9) was verified. Thus, it is possible to measure He molar fraction from measured gas parameter.

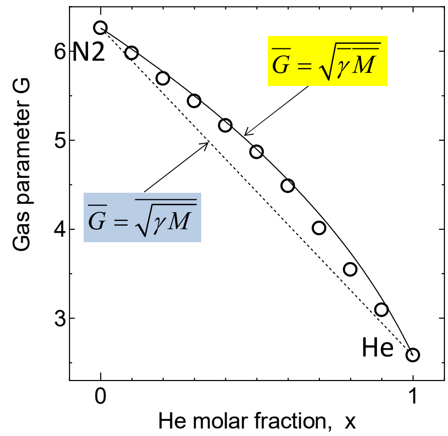

Fig. 5 Gas parameter against He molar fraction

Conclusions

A method of background gas analysis with leaky attenuation in ball SAW sensor was proposed and the accuracy of the proposed method was verified.

References

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