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Real-time monitoring of methanol concentration using shear horizontal surface acoustic wave sensor

横波型弾性表面波センサを用いたメタノール濃度の実時間測定

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1. Introduction

In recent years, there is an increasing demand for sensors which continuously perform sensing to detect the abnormality such as quality control sensor for water or oil and concentration sensor for fuel cells. These existing sensors are large and expensive. In this study, we suggest the sensor using a shear horizontal surface acoustic wave (SH-SAW) device which is small size and relatively low price. The SH-SAW device can detect the identification and concentration of liquids because it immediately responses to change of the physical properties of the liquid. However, the SH-SAW sensor is necessary to calibrate at each measurement for accurate measurement. Therefore, an objection of this study is developing a method for continuous measurement and considering the correction method. In this study, we selected the direct methanol fuel cell (DMFC) as an example of the application to continuous liquid concentration measurement.(1) The methanol concentration, which is the fuel of DMFC, was continuously measured. Moreover, we also examined a method for correcting the influence of the conductivity of the formic acid generated at high temperature.

2. SH-SAW sensor

Floating electrode unidirectional transducers were fabricated on 36YX-$LiTaO_3$. The center frequency of the SH-SAW sensor used was 155 MHz. There are two-channel configuration with open or short channels. The short channel can detect only mechanical properties of liquid. On the other hand, the open channel can detect mechanical and electrical properties of liquid. At the measurements, the differential signals between short and open channels were detected to obtain the electrical properties of the liquid. **Figure 1** shows the experimental system of this study. Phase and amplitude of the SH-SAW sensor were detected by a vector voltmeter.

3. Concentration determination method

The SH-SAW sensor requires to calibrate at each measurement. However, when the SH-SAW sensor is inserted into the liquid-flow-tube of the DMFC, it is difficult to measure the reference

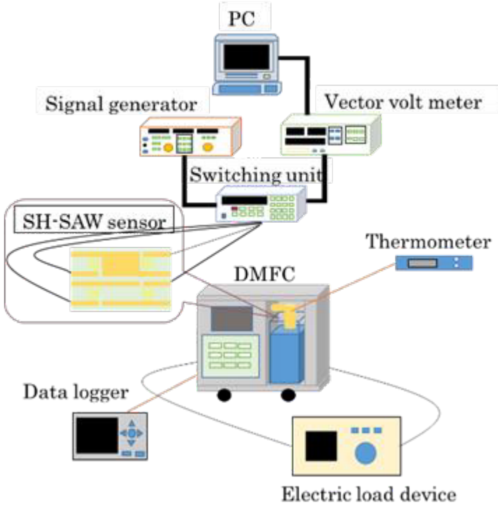

Fig. 1　Experimental system.

liquid. Therefore, the concentration determination method has been devised. (2) This is the calculation method that reference measurement performed only once time before the installation. The obtained data was used in the theoretical calculation.

In the concentration determination method, the phase shift obtained by the SH-SAW sensor was used. In the previous method,(2) we assumed that the relationship between the concentration and the phase shift did not depend on the temperature. However, in this study, we considered that the relationship depends on the temperature. In order to verify the temperature dependence of α, it was determined the relationship between concentration and phase shift at each temperature from experiments. **Figure 2** shows coefficient α from 10 to 60 ˚C. The relational expression of the concentration and the phase shift including the temperature term derived from Fig. 2 is the following.

$$\text{Concentration} = (-0.0018\times\text{Temperature}+0.2038)\times\text{Phase shift} \quad (1)$$

From eq. (1), it found that the relationship between the concentration and the phase difference is not constant, the coefficient α decrease with temperature rising. **Figure 3** shows concentration estimate calculated by eq. (1). In this paper, we evaluate the concentration of the methanol after steady state condition. The estimated concentration is within 2 and 3 wt%, which is a reasonable concentration. In addition, it was possible to reduce the influence of temperature variation in the concentration estimated in Fig. 3.

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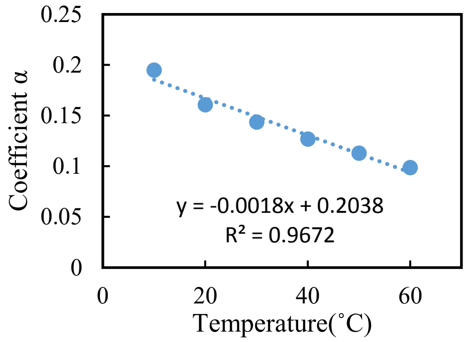

Fig. 2 The temperature dependence of the coefficient α.

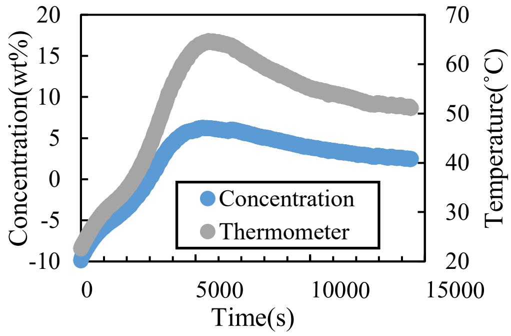

Fig. 3 Estimated methanol concentration.

4. Conductivity corrected method

When the fuel temperature is above 70 ˚, the influence of the formic acid must be considered. In previous research,(2) the correction method was proposed. In this study, we improve the correction method. In the method, it corrects by incorporating apparent conductivity to the theoretical value. As the amplitude of SH-SAW is affected by the conductivity, the amplitude change was used to estimate the conductivity. **Figure 4** shows the estimated concentration with and without the considering of the influence of the conductivity. The fuel temperature exceeds 70 ˚C in this measurement. Therefore, the concentration before correction shows slightly higher value due to the conductivity of formic acid. On the other hand, the concentration with the correction exists between 2 and 3 wt%.

Concentration and conductivity, which were measured by the conventional density meter and conductivity meter, are summarized in **Table. 1**. Compared the results in Figs. 3 and 4 with Table.1, the estimated results at the steady state condition of the DMFC are reasonable.

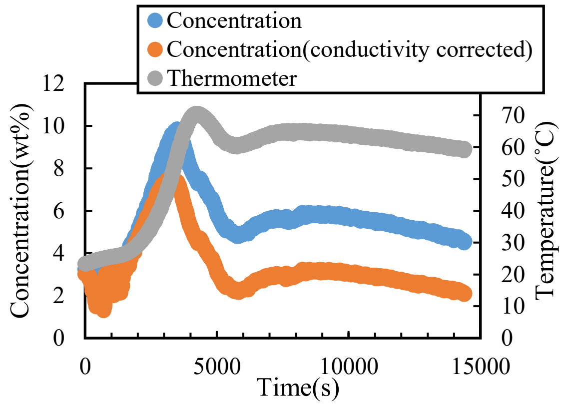

Fig. 4 Estimated concentration with considering the influence of the formic acid.

Table. 1 Concentration and conductivity evaluated by density meter and conductivity meter.

	Density(kg/m^3)	Concentration(wt%)	Conductivity(S/m)
Fig.3	1.052E-03	2.773	2.450E-02
Fig.4	1.051E-03	3.577	2.240E-02

5. Conclusion

In this study, we examined the temperature and conductivity correction in the concentration determination method. Previously, we considered that the relationship of concentration and phase shift was constant. In this paper, however, we considered that the relationship depends on the temperature. Then we derived the new equation and used it to estimate the methanol concentration. The results indicate that the estimated concentration is the reasonable value. Moreover, the influence of the formic acid was discussed. When the fuel temperature is higher than 70 °C, we found conductivity correction using the result of the amplitude is necessary. In the future, also we have to discuss concentration estimation method in DMFC warm-up state.

Acknowledgement

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