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Appendix A

Software Codes

The data acquisition and theanalysis program for gas sensor signals were written and developed using Turbo Pascal language. The pseudocodes of these programs are given below.

A.1 Data Acquisition Program

Construction	Description
Program	
Initialize: array of data A(t) ← 0	set the initial value of data array and time
t ← 0	index to zero
Assign: t_{max} ← measuring time	assign a value of maximum time
Initialize: A/D converter	
Repeat	start measurement
Start A/D converter	send the start command to A/D
While [not EOC]	check EOC (end of conversion) status
Polling	request the status from A/D
End While	
A(t) ← [A/D]	Assign A(t) with the data in A/D register
t ← t + 1	increment time index
Until [t = t_{max}] or [Stop]	stop measurement if t = t_{max} or stop command receive
Write: A(t) → File	Save data to file
End Program	

A.2 Analysis Program

Construction	Description
Program	
Read: A(t) ← File	Read data from file
Partition A(t)	Determine the number of peak in A(t)
n ← Peak	Assign n with the number of peak
For [i = 1,2,…,n]	
Module: signal base line	Procedure to find the base line of sensor signal
Module: signal peak	Procedure to find maximum signal
Module: recovery time	Procedure to find recovery time.
Sensitivity(i) ← peak(i)/base line(i)	Assign sensitivity
End For	
Write Sensitivity(i) & recovery time(i) to file	Save analysis data to file
End Program	

Appendix B

Preliminary Study of Effect of Frequency on Gas Measurement

It is well know that the adsorption of gas molecule affects not only the conduction mechanism of electrons in semiconductor materials but also the surface structure. This may be observed by monitoring through the change of sensor capacitance or work function. However, both parameters must be measured in AC mode. In this study, we performed a gas measurement at different frequency ranging from 100 Hz to 100 kHz and monitored the change of sensor impedance and phase simultaneously. Here, we expected that the additional data of the phase change would give us more information on gas detection.

B.1 Experimental Setup

SnO_2 powder was prepared by the identical processes described in Chapter IV. This SnO_2 was sintered at 600 °C for 3 hours and then painted on a glass substrate with Ti/Pt electrodes. This sensor was installed in a flow through system as show in Fig. B.1. The sensor impedance and phase was monitored via HP 4474A multi-frequency LCR meter. The software for data acquisition were developed by Turbo Pascal language. The conditions for the experiments is lists in Table B.1.

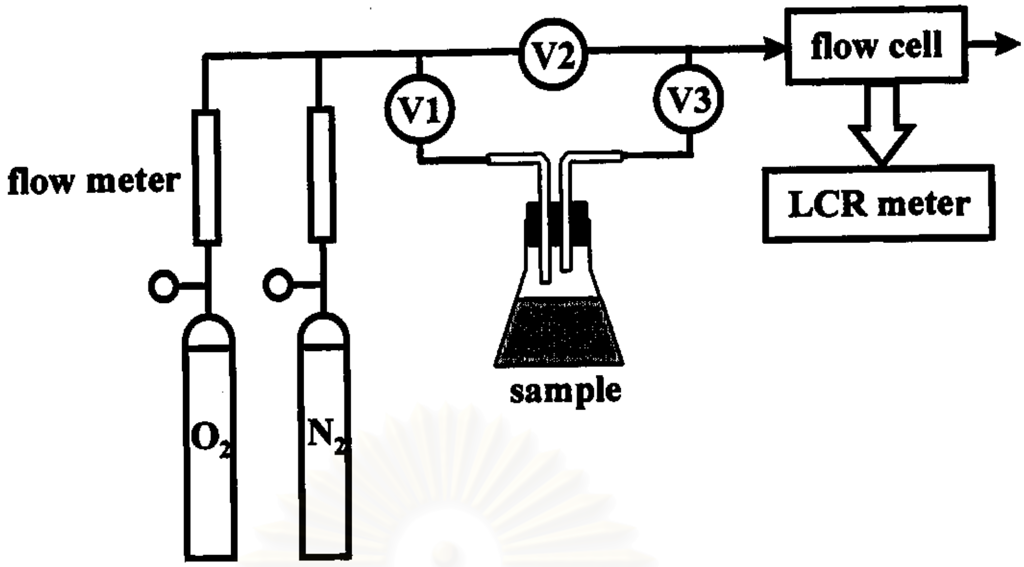


Fig. B.1 Experimental setup: V1, V2 and V3 in the picture are solenoid valve

Table B.1 Conditions for the experiments

Parameters	
Applied voltage	5 V_{peak} sinusoidal 0.1-100 kHz
Operating temperature	150-350 °C
Gas sensors	SnO_2 thick film gas sensor sintered at 600 °C
Flow rate of carrier gas	50 ml/min (O_2 10 ml/min and N_2 40 ml/min
Test sample	Ethyl alcohol 0.0001-10 % by volume

B.2 Results and Discussion

Fig. B.2 shows impedance and phase of gas sensor in air as a function of frequency. In the range of measurement frequency, the values of impedance were nearly constant, while, phase decreased slightly with frequency. The effect of frequency on gas response was investigated and the results are shown in Fig. B3. It is clear that the change of frequency had not much effect on the change of impedance with gas ambient, while the phase change increased with the operating frequency. Therefore, we select to perform the gas response characteristics at 100 kHz.

Moreover, at very low frequency, the detection of phase change is difficult, since the signal to ratio become very low as seen in Fig. .B.3.

Fig. B.4 shows the plot of sensitivity (Z_{air}/Z_{gas}) and Δphase against temperature under 1 % of EtOH measured at 100 kHz. The profile of both sensitivity and Δphase were the sample shape, except they exhibited the maximum value at different temperature. Fig. B.5 shows the calibration curve for both sensitivity and Δphase. Both of them had the similar characteristics and obeyed to the power law model.

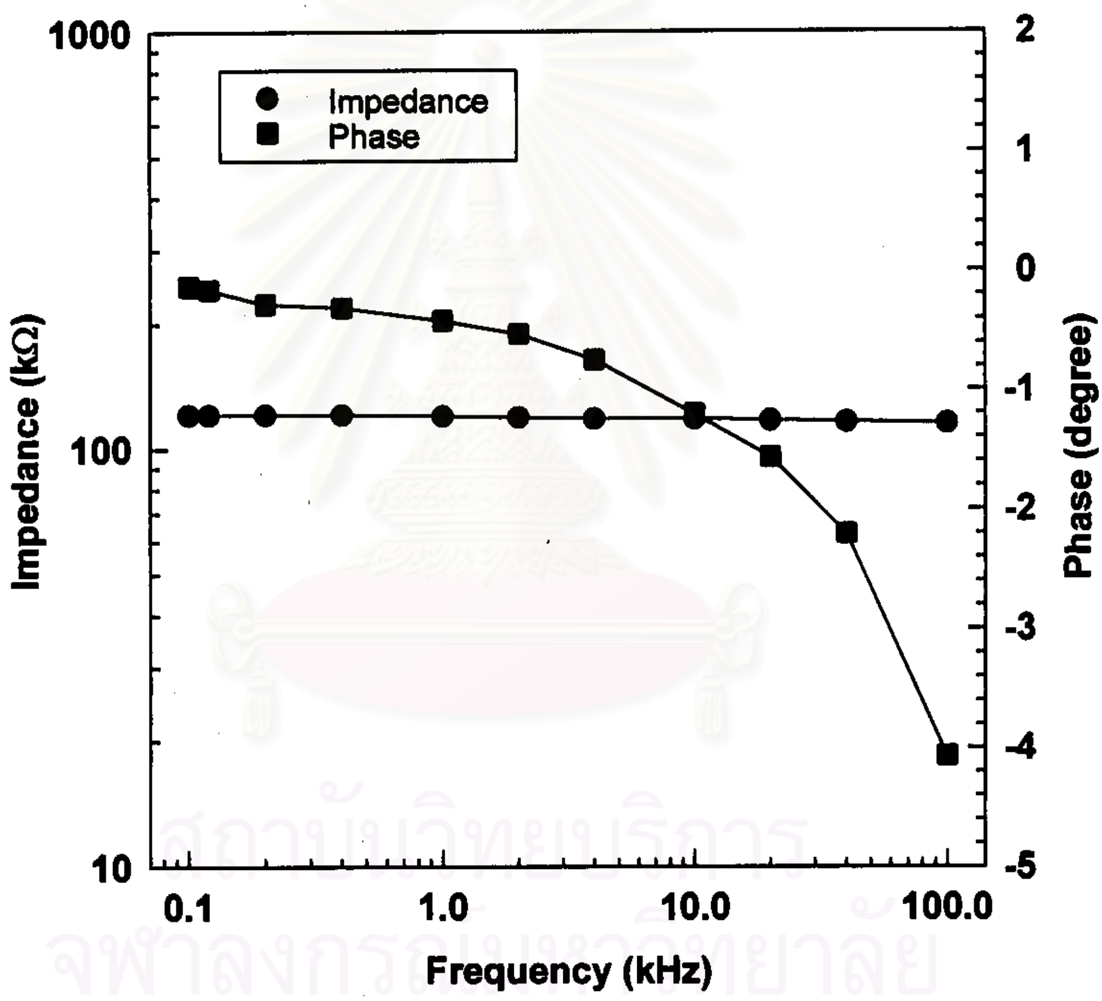
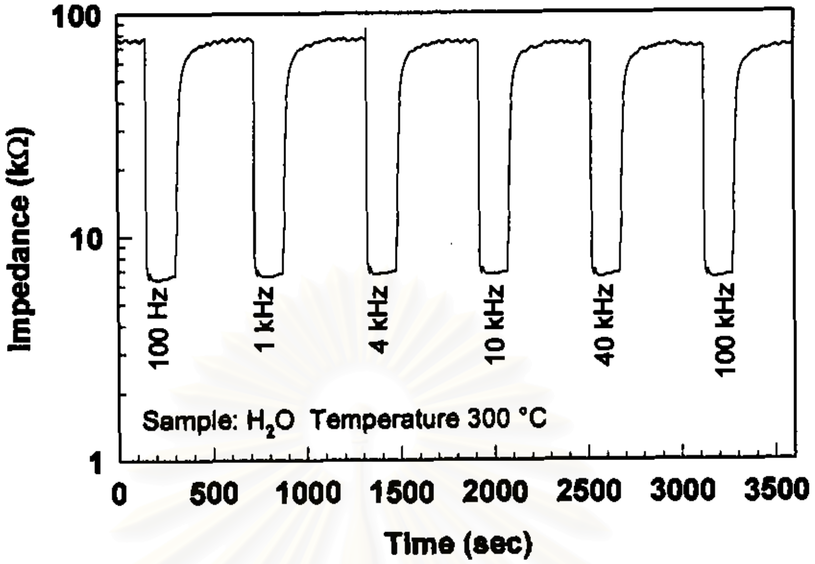
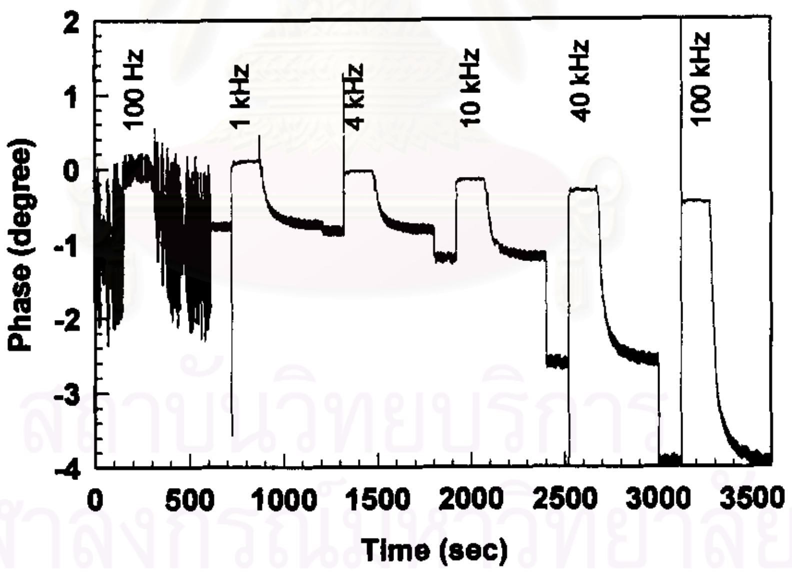


Fig. B.2 Plot of sensor impedance and phase at different frequency.



(a)



(b)

Fig. B.3 Gas response as a function of operating frequency: (a) the change of impedance and (b) the change of phase

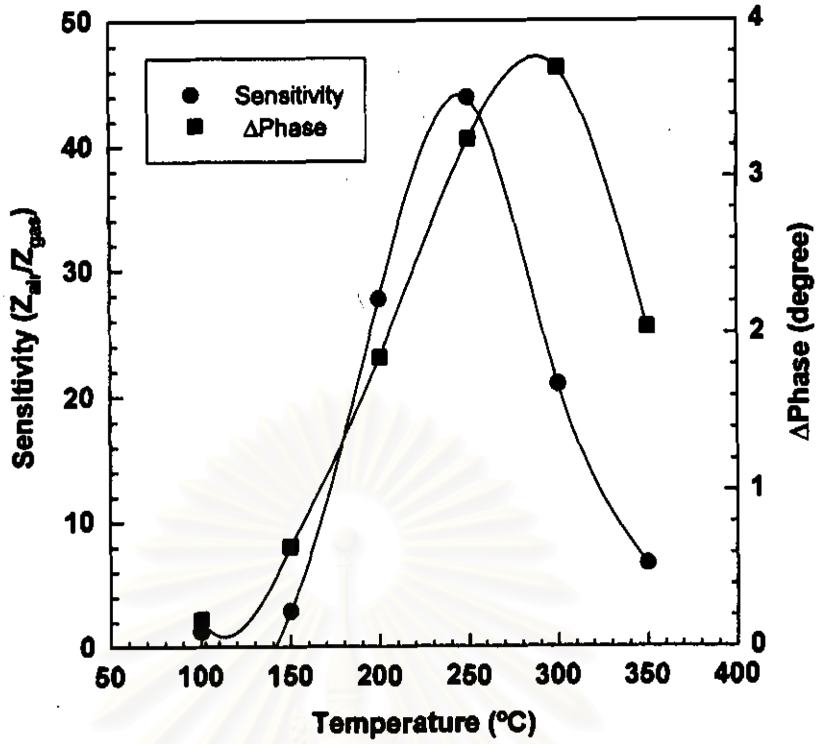


Fig. B.4 Plot of sensitivity against temperature under 0.1 % EtOH.

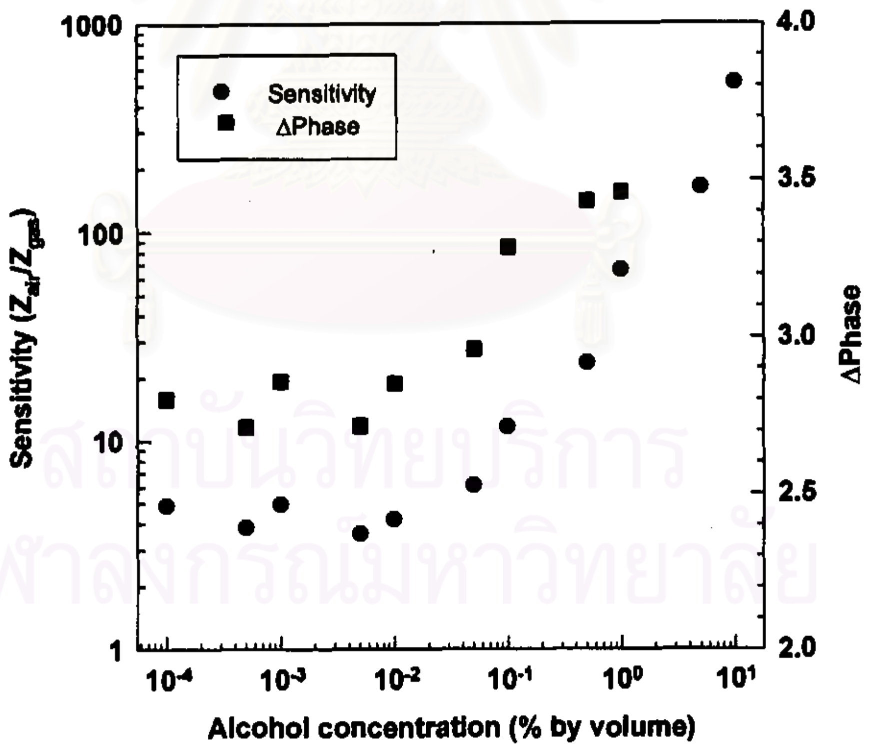


Fig. B.5 Calibration for alcohol detection in the case of (a) sensitivity and (b) Δphase.

However, it should be reminded that the change of phase that increase with the measurement frequency, may not give us any further information of the capacitance change (surface structure) due to gas adsorption. This can be shown by a simple analysis.

If we assumed that the equivalent circuit of a gas sensor may be represented a simple parallel RC circuit. Thus, the ac sensitivity of a gas sensor can be defined as follows.

$$S = \left|\frac{Z_{air}}{Z_{gas}}\right| = \left|\frac{R_{air} / \sqrt{1+(\omega R_{air} C_{air})^2}}{R_{gas} / \sqrt{1+(\omega R_{gas} C_{gas})^2}} \exp\left[j(\theta_{air} - \theta_{gas}\right]\right| \qquad \text{(B.1)}$$

where $\theta_{air} = \arctan(-\omega R_{air} C_{air})$ and $\theta_{air} = \arctan(-\omega R_{gas} C_{gas})$. Here, we defined the phase change (Δ Phase) as follows.

$$\Delta\text{Phase} = \theta_{air} - \theta_{gas} = \arctan\left(\frac{\omega(R_{air} C_{air} - R_{gas} C_{gas}}{1+\omega^2 R_{air} C_{air} R_{gas} C_{gas}}\right) \qquad \text{(B.2)}$$

As can be seen from Fig. B3a, the changes of sensitivity are independent to the measuring frequency. Thus, we may conclude that, $(\omega R_{air} C_{air})^2 << 1$ and $(\omega R_{gas} C_{gas})^2 << 1$, consequently, the expression of Δ Phase can be written in the more simpler form.

$$\Delta\text{Phase} = \arctan(\omega(R_{air} C_{air} - R_{gas} C_{gas})) \qquad \text{(B.3)}$$

Moreover, in some cases that the capacitance changes are very small ($C_{air} \approx C_{gas}$) due to the limitation of sensor structure, the phase change will reflect the change of sensor resistance. The measurement in ac mode should be performed using the sensor with a special structure that exhibits a large change of capacitance.

B.4 Summary

The preliminary study has showed that there is a feasibility use semiconductor gas sensor in an AC mode of operation. In this mode measurement, the data of phase change can be gained simultaneously with the change of impedance. Both of this information could be used together for understanding the detection mechanism of gas sensors.

Appendix C

Publication Lists

Domestic Conferences

[1] A. Teeramongkonrasmee, M. Sriyuthusak, T. Cholpranee, M. Sawadsaringkarn and S. Panyakeow, "Fabrication of Oxygen Sensor", The Conference of the Engineering Institute of Thailand, Under H.M. The King's Patronage, Bangkok, October 5-8, 1994.

[2] A. Teeramongkonrasmee and M. Sriyuthusak, "Study of Characteristics of Thin Tin Oxide Film Prepared by Sol-Gel Technique", Proceeding of the 18th Conference of Electrical Engineering, Mahanakorn Technology University, November 22-24 1995, pp. 494-498.

[3] A. Teeramongkonrasmee and M. Sriyuthsak, "Fabrication of Thin Film Type Ammonia Gas Sensors by Sol-Gel Technique", Proceeding of the 19th Conference of Electrical Engineering, Khon Kaen University, November 7-8 1996.

[4] K. Anothainart, A. Teeramongkonrasmee and M. Sriyudthsak, "Fabrication of Tin Oxide-Based Thick Film Gas Sensors", Proceeding of the 19th Conference of Electrical Engineering, Khon Kaen University, November 7-8 1996.

[5] K. Anothainart, A. Teeramongkonrasmee and M. Sriyudthsak, "Fabrication of SnO_2-TiO_2 Gas Sensors", Proceeding of the 20th Conference of Electrical Engineering, Chulalongkorn University, November 13-14, 1997.

[6] A. Teeramongkonrasmee and M. Sriyudthsak, "Effect of Series Resistance in Gas Measuring Circuit on Sensor Sensitivity and Recovery time" Proceeding of the 20th Conference of Electrical Engineering, Chulalongkorn University, November 13-14, 1997.

International Conferences

[1] T. Moriizumi, A. Teeramongkonrasmee and M. Sriyudthsak, "Fabrication of SnO_2 Gas Sensor by Sol-Gel Technique", Proceeding of the 42th Conference of Japanese Applied Physics, Spring Secition, Toukai University, Tokyo, Japan, March 27-30 1995.

[2] A. Teeramongkonrasmee and M. Sriyudthsak, "Thin Film Type Ammonia Gas Sensor by Sol-Gel Technique", Regional Symposium on Materials Science: Fundamentals and Applications in Semiconductors and Superconductors, National Engineering Center, University of the Philippines, Diliman, Quezon City, Philippines, December 19-12, 1996

[3] A. Teeramongkonrasmee and M. Sriyudthsak, "Sol-Gel Derived Tin Oxide Thin Film Gas Sensors", The 7th International Meeting on Chemical Sensors (IMCS-7), Beijing International Convention Center, Beijing, China, July 27-30, 1998.

International Journal

[1] A. Teeramongkonrasmee and S. Sriyudthsak "Probelms in Gas Sensor Measuring Circuit and Propose of a New Circuit" to be published in Sensors and Materials.

[2] A. Teeramongkonrasmee and S. Sriyudthsak "Sol-Gel Derived Tin Oxide Thin Film Gas Sensors" submitted to Sensors and Actuator B (Chemical).

Biography

Mr. Arporn Teeramongkonrasmee was born in Bangkok, Thailand on April 21, 1970. He received his Bachelor degree in electrical engineering from Chulalongkorn University in 1991 and Master degree in electrical and electronics engineering from Tokyo Institute of Technology in 1994.

In 1994, he received the excellent presentation award from The institute of Electrical and Electronics Engineering (IEEE) Japan from the paper titled with "LB Film Patterning Technique and Its Application to SAW Chemical Sensor". In 1994, he entered Ph.D. program at Chulalongkorn University. His current interests are in the field of gas sensors and semiconductor technology.