

Final Report

(written in 25/02/2007)

<Principal Investigator>

Kiyoshi Toko, Prof.

<Institution & address>

Kyushu University, Japan

744 Motooka, Nishi-ku, Fukuoka,

819-0395 Japan

<Contract Number>

FA5209-05-P-0240

Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE 07 AUG 2007		2. REPORT TYPE FInal		3. DATES COVERED 24-01-2005 to 23-02-2007	
4. TITLE AND SUBTITLE Development of Odor Sensor to Recognize Partial Structures of Chemical Substances				5a. CONTRACT NUMBER FA520905P0240	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Kiyoshi Toko				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Graduate School of Information Science and Electrical Engineering, Kyushu University, Hakozaki, Fukuoka 812-8581, Japan, jp, 812-8581				8. PERFORMING ORGANIZATION REPORT NUMBER N/A	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) AOARD, UNIT 45002, APO, AP, 96337-5002				10. SPONSOR/MONITOR'S ACRONYM(S) AOARD	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S) AOARD-054014	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT The aim of this research is to develop an odor sensor information system that can resolve molecular information into the information of partial structures, the so-called artificial olfactory epithelium. Furthermore an attempt was made to quantify odor using molecular information					
15. SUBJECT TERMS Electrodes, Membranes, Odor Detection, Self-Assembled Monolayers					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 7	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

◇ **Objective**

In recent studies, Dr. L. Buck and Dr. R. Axel, who received Nobel Prize in Medicine in 2004, revealed the biological odor recognition process. According to their researches, the odor receptor receives odor molecules with recognizing molecular information. At length, the odor receptors recognize not whole structure of odor molecules but their common properties, called odotope. Therefore, molecular information can be regarded as the key to odor quantification, and it requires the sensor system with resolving the molecular information into their properties in order to recognize several kinds of odor flexibly. The aim of our research is to develop the odor sensor system which can resolve molecular information into the information of partial structures, so-called artificial olfactory epithelium. Furthermore, we attempt to quantify odor using molecular information.

◇ **Status of Effort**

In this study, an electrochemical cell was utilized for odor detection. There are an enormous number of odor receptors on the biological olfactory epithelium; therefore, the artificial olfactory epithelium also composes of multichannel reception sites. Furthermore, we developed the water membrane of the electrolyte solution (100 mM KCl and 60 % glycerin) to trap odor molecules flown in the air like nasal mucus. Fig 1 shows the artificial olfactory epithelium chip developed here.

In the measurement, we have done an electrochemical impedance measurement. In this study, hydroxyl group and aromatic ring were chosen as detection targets; then, we attempted to evaluate odors of aromatic alcohols quantitatively. Therefore, we have attempted to develop each channel with specificity to these partial structures. For the channel for hydroxyl group, we have added the ion-exchange resin into the water membrane to make the interaction between sensor surface and hydroxyl group active. For the channel for aromatic ring, we have formed a rough hydrophobic surface by competitive adsorption of benzene and 1 - octanethiol which can form self-assembled monolayer (SAM) [Figure 2]. This surface can be thought as the surface with affinity to hydrophobic partial structure like aromatic ring and with the roughness based on the shape of aromatic ring. Finally, we attempted to evaluate the change in odor induced by the concentration changes quantitatively using the technologies above.

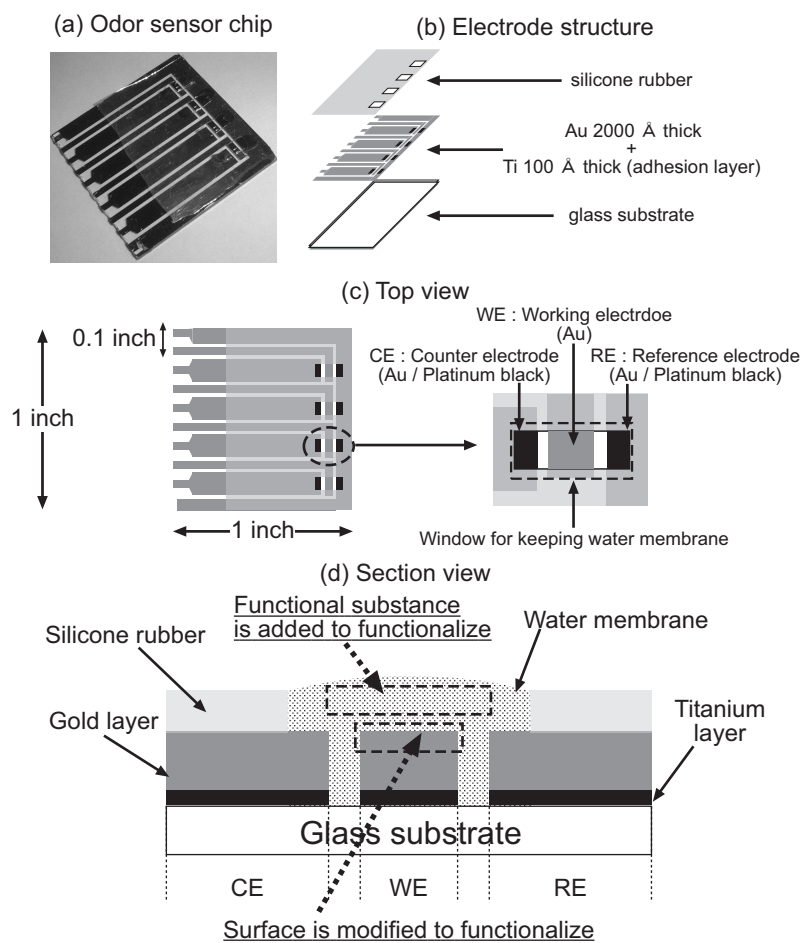


Figure 1: Artificial olfactory epithelium chip

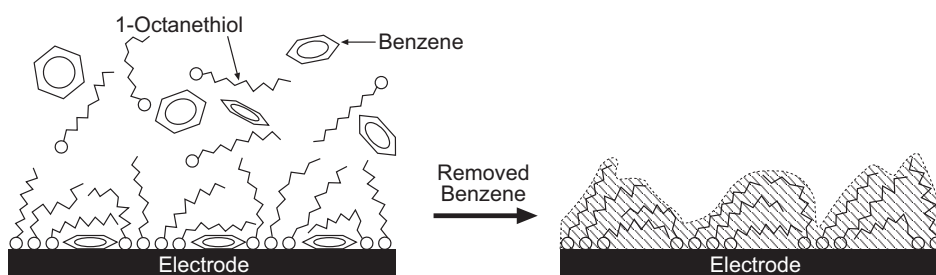


Figure 2: Channel for aromatic ring

◇ **Abstract**

The responses to odor molecules are represented by the change in the real part of electrode impedance ΔR_e . We can evaluate the result by comparing the responses of 3 channels; "global" channel, "hydroxyl group" channel and "aromatic ring" channel. "Global" channel stands for the channel which is composed of no-addition to the water-membrane and no-modified surface, and it is regarded as a reference of the response of odor molecules. In this study, we measured ethanol which has hydroxyl group, benzene which has aromatic ring, and phenethyl alcohol which has both hydroxyl group and aromatic ring in its structure. Figure 3 shows their response with 3 channels.

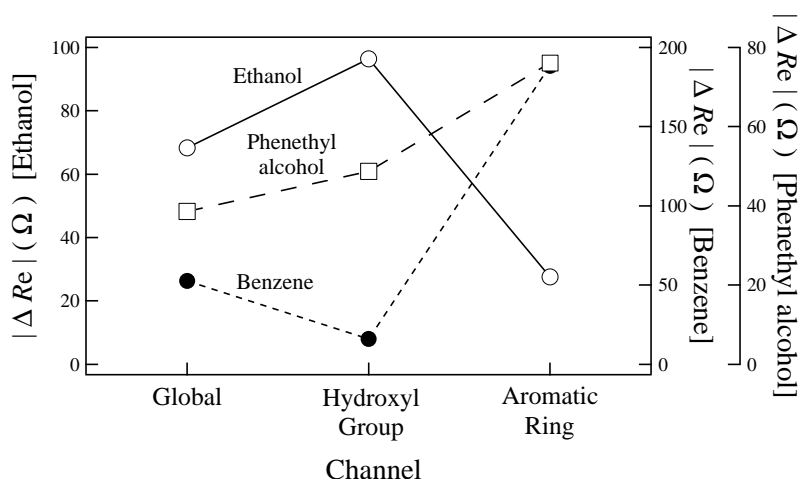


Figure 3: Response to ethanol and benzene with both channels

From Fig 3, the hydroxyl group channel responded to ethanol largely rather than with global channel, when it responded to benzene less than with global channel. P cellulose, included in the hydroxyl group, is cation-exchange resin, so pH of the water membrane is decreased since K^+ ion is exchanged into H^+ ion. This pH change might influence the detection of ethanol. On the other hand, the reason for the less response to benzene with hydroxyl group channel might be that the adsorption of benzene onto the surface was blocked by the interaction between benzene and P-cellulose. In this way, the addition of P cellulose to the water membrane can be operated

as the hydroxyl group channel.

On the other hand, the channel for aromatic ring responded to benzene well but not to ethanol so much. It might be because the electrode surface covered by the alkane chain of 1 - octanethiol is hydrophobic. Therefore, this hydrophobic surface can interact with hydrophobic partial structure such as aromatic ring, and it might block the adsorption of hydrophilic partial structure to the surface such as hydrophilic partial structure such as hydroxyl group. In this way, the rough hydrophobic surface can be operated as the aromatic ring channel.

From the result of phenethyl alcohol, both channels responded to it. It can be thought that each channel recognized not whole structures of odor molecules but the partial structures. In this way, the electrode surface could be functionalized by controlling the composition of water membrane and surface modification.

Using those results, we attempted to evaluate the odor of phenethyl alcohol quantitatively based on these partial structures. The odor evaluation is done by the intensities of hydroxyl group and aromatic ring. These intensities are calculated by the following relational expressions between response value and concentration.

$$\begin{aligned}\Delta R_e(\text{Ethanol}) &= a_{\text{alcohol}} * \log [\text{Ethanol}] + b_{\text{alcohol}} \\ \Delta R_e(\text{Benzene}) &= a_{\text{aroma}} * \log [\text{Benzene}] + b_{\text{aroma}}\end{aligned}$$

Then, the intensity of phenethyl alcohol was estimated using the equations above. In this study, we attempted to represent the change in the odor of phenethyl alcohol by concentration [shown in Fig 4].

From Fig 4, all results are plotted closer to axis of I_{aroma} ; therefore, this result indicates that the odor of phenethyl alcohol is dominated by aromatic ring rather than hydroxyl group. Furthermore, the results at lower concentration and at higher concentration are plotted closer to dashed line; however, the results at medium concentration are plotted far from the dashed line. Phenethyl alcohol at lower concentration smells like rose, but that at higher concentration smells like green grass or medicines. As the odor is also depended on the concentration, the results of Fig 4 stand for the change of the odor quality by concentration. In this way, we can indicate the possibility the odor can be quantified based on molecular information using the artificial olfactory epithelium.

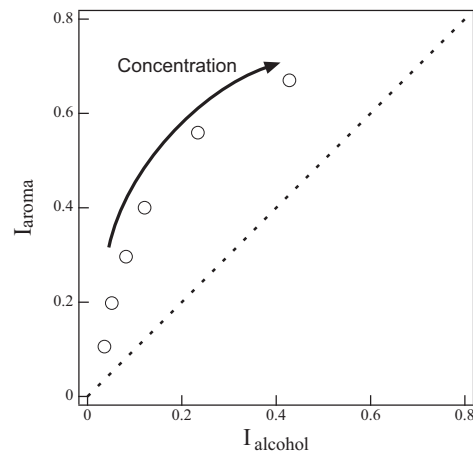


Figure 4: Odor quantification of phenethyl alcohol

◇ Personnel Supported

- Kiyoshi Toko, Dr.
Professor, Graduate School of Information Science and Electrical Engineering, Kyushu University, Japan
- Kenshi Hayashi, Dr.
Associated Professor, Graduate School of Information Science and Electrical Engineering, Kyushu University, Japan
- Ryosuke Izumi
Guest Researcher, Graduate School of Information Science and Electrical Engineering, Kyushu University, Japan

◇ Publications

- Development of Artificial Olfactory Epithelium, R. Izumi, S. Etoh, K. Hayashi, K. Toko, *Proc. Asia-Pacific Conference of Transducers and Micro-Nano Technology-APCOT 2006 (June 25-28, 2006, Singapore, Singapore)*, 95-CSM-A0262, 2006.

◇ **Interactions**

(a) Participation/presentations

- Development of Artificial Olfactory Epithelium (Oral), R. Izumi, S. Etoh, K. Hayashi, K. Toko, *Asia-Pacific Conference of Transducers and Micro-Nano Technology-APCOT 2006 (June 25-28, 2006, Singapore, Singapore)*, 2006.

(b) Utilization of our knowledge

None

◇ **New**

None

◇ **Honors/Awards**

None

◇ **Archival Documentation**

None