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Characterization of ion sensitive extended-gate field effect transistor coated by functional self-assembled monolayer

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Abstract

Extended-gate field effect transistors (FETs) were characterized by modifying self-assembled monolayers (SAMs) of alkanethiols with functional groups and mercaptophenylboronic acid (MPBA) on the gate surface. The SAMs with carboxyl and amino terminal groups on the gate surface of FET showed the specific ion sensitivity. The MPBA-coated gate FET showed pH response as well, and its affinity with glucose drastically increased at the alkaline solution (pH>8) judging from the shift of gate surface potential in the FET. From these result, the SAM-based FET is applicable to the biosensor by designing the gate interface with respect to a variety of the target substance.

1. Introduction

A field effect transistor (FET) is expected for a label free and low cost biosensor using the principle of semiconductor. The change of electron density at the channel in the FET is transduced as the shift of gate surface potential owing to chemical or biochemical events so that the FET biosensor allows the highly sensitive detection of small molecules or ions [1-4]. Moreover, the extended-gate FET has been investigated for some advantages of the allowance to separate target recognition part from semi-conductive device. Using the extended-gate FET, therefore, it is possible to select the gate material and modify on the gate surface freely so as to recognize the target substances [5].

Self-assembled monolayers (SAMs) are widely used as the functional membrane with highly ordered structure. The SAMs can be formed by the surface modification method and give various chemical features to inorganic surface [6, 7]. In the present study, we investigated the possibilities of ion sensitive extended-gate FET as the biosensing platform by forming the SAMs with a variety of terminal groups on the extended-gate gold electrode, and analyzed the fundamental characteristics of various SAMs.

2. Evaluation of ion sensitive extended-gate field effect transistor

Four alkanethiols, of which their terminal groups were methyl (-CH_3), hydroxyl (-OH), amino (-NH_2), and carboxyl (-COOH), were used as the SAM formation, respectively. A gold sputtered substrate was immersed in each alkanethiol diluted ethanol solution of 1 mM for 24 hours, resulting in that the SAMs were formed by Au-S bond. Fig. 1 showed the result of contact angle for each Au surface after the SAM formation. After equilibrated by phosphate buffer, the extended Au/SAM gate FET was fabricated and the changes in the surface potential was observed when the pH of buffer solution was varied from 6 to 8 in the range of 10, 200, and 500 mM phosphate buffer, respectively. As shown in Fig.2, the carboxy- and amino- terminal group-based SAM gate FET showed the definite response of gate surface potential to pH changes, while the methyl- and hydroxyl- terminal group-based SAM gate FET did not change so clearly, although the ion strength of solution shown in Fig.2 was 10 mM only. About 30 mV of voltage shift per pH were observed in the carboxy- and amino- terminal group-based SAM gate FET, besides the shift in output were getting clearer as the concentration of phosphate buffer became higher, although it is said that the Debye length would be shorter as the ion strength became higher.

On the other hand, the pH dependency and the reactivity to glucose was evaluated using the PBA-SAM gate FET. The PBA-SAM gate FET also showed pH response as the same as –COOH and –NH_2 alkanethiol SAM gate FET. The PBA derivative contains boron atom and covalently bound to two hydroxyl groups in the ground state. The PBA keeps the equilibrium between the neutral state and

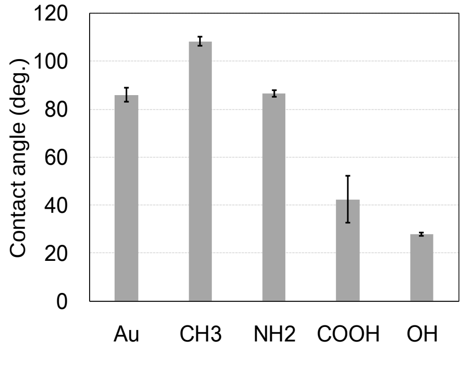

Fig. 1: Contact angle of various SAMs treated Au surface (Au: w/o SAM treatment, and others were indicated as the terminal group of alkanethiol)

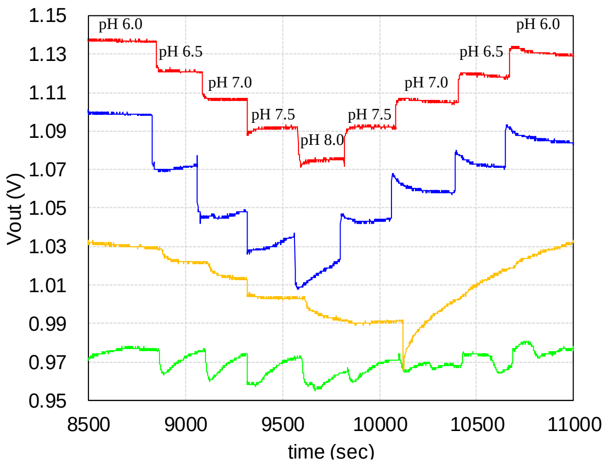

Fig. 2. Time course for surface potential changes of various SAM-gated FET at different pH (SAM of terminal group were indicated as colored line, Green: $-CH_3$, Yellow: -OH, Blue: $-NH_2$, and Red: -COOH.)

the ionic state depending on the dissociation constant, p*Ka* [8]. Therefore, it was considered that the FET detected the increase or decrease of negative charge of boron atom by dissociation of PBA in accordance with the changes of hydrogen ion concentration. As a result of that, the PBA-SAM gate FET showed pH responsive.

The binding affinity of PBA-SAM to glucose was investigated at the different pH solution in the range of pH 5-12 (Fig. 3). After the addition of glucose, the gate surface potential was drastically changed at pH 8, and the large shift was observed at alkaline solution particularly. On the other hand, the gate surface potential did not shift so much at acid to neutral range. It was proved that the equilibrium of PBA was likely to shift from neutral to negative, and it was easy to form the PBA complex with glucose at the higher pH. Though it has been reported that the p*Ka* of PBA was 8.6 originally [9], it was proved that the interaction of PBA with glucose had been promoted at slightly lower pH than the p*Ka* of PBA at around the gate/solution interface.

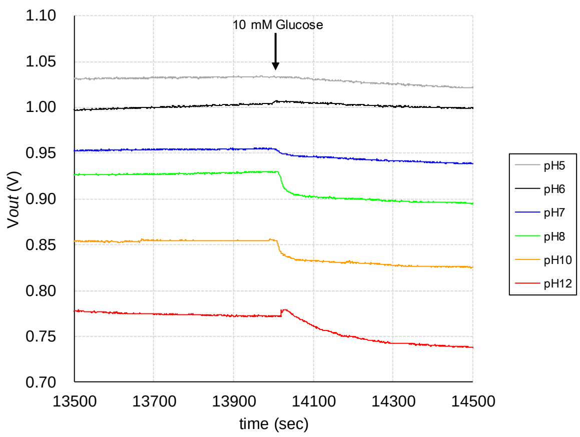

Fig. 3: Time course for surface potential changes of PBA SAM in different pH when 10 mM glucose added.

3. Conclusions

Ion sensitive extended-gate FET was investigated using alkanethiol SAM with various kinds of groups and PBA-SAM. The carboxy- and amino- terminal group-based SAM gate FETs showed the good ability to pH sensitivity. Moreover, the interaction of PBA-SAM with glucose at the gate/solution interface in the different pH was analyzed, resulting in that the affinity of PBA with glucose drastically increased in alkaline solution (pH >8). The fundamental characterization of the gate interface in the FET would be useful for the practical use in the future.

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