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Sensitivity Enhancement for Reaction between Drosophila LUSH odorant-binding Protein and Ethanol using Dual-Gate EGFETs

In-Kyu Lee[1], Tae-Eon Bae[1], Hui-Chong Lau[2], Jeong-Ok Lim[2], Jae-Young Kwon[3], Tae-Jun Ha[1], and Won-Ju Cho[1]

[1]Kwangwoon Univ., Department of Electronic Materials Engineering, 447-1, Wolgye-dong, Nowon-gu, Seoul 139-701, Korea, Phone: +81-2-940-5163, E-mail: chowj@kw.ac.kr
[2]Kyungpook National Univ., Bio Medical Research Institute, 44-2 Samduk-2ga, Jung-gu, Daegu 700-721, Korea
[3]Sungkyunkwan Univ., Department of Biological Sciences, 2066, Seobu-ro, Jangan-gu, Suwon 440-746, Korea

Abstract

To detect the reaction between drosophila LUSH odorant-binding protein and ethanol, we fabricated the differential-measurement biosensor using two extended-gate field-effect-transistors (EGFETs), which are composed of both a sensing part and a FET part. For the enhancement of reaction sensitivity, we used the SOI-MOSFETs with dual-gate operation. As a result, we successfully detected the reaction between LUSH and ethanol through the electrical signals

1. Introduction

Extended-gate filed-effect-transistors (EGFETs) are a biosensor detecting the ion-concentrations in the electrolyte, and composed of both a sensing part and a FET part [1]. Despite their a lot of advantages such as a small size, a simple structure, a fast response speed, and a CMOS compatibility [2], the conventional single-gate (SG) EGFETs have a problem, which is that they have a poor sensitivity that exposes the limitation of Nernstian pH response with a theoretical maximum value of 59 mV per pH. For this reason, it is difficult for them to detect the reaction of materials with low reaction magnitude. In order to solve this problem, the dual-gate (DG) EGFETs pH sensors using fully-depleted (FD) silicon-on-insulator (SOI) MOSFETs are proposed. The DG operation of SOI-MOSFETs stems from a capacitive coupling between top and bottom gate capacitance, and it leads excessively enhanced sensitivity. In case of the SG EGFETs, a reference electrode at the top of the sensing membrane holds the electrolyte potential, and allows electrostatic coupling with the channel of the transistor. On the other hand, the DG EGFETs can control the optimum bias conditions using the bottom gate electrode as well as the reference electrode. Meanwhile, the LUSH is an odorant-binding protein expressed in the olfactory organs of Drosophila melanogaster, and it is well-known as responding to various types of alcohol, such as ethanol, butanol, and propanol. However, it has not yet been investigated to detect the reaction thorough the electrical signal by using FET device.

In this work, therefore, we fabricated the DG EGFETs using SOI-MOSFETs and evaluated the reaction between LUSH and ethanol using them. Also, to confirm the reaction specifically, we developed a differential-measurement system, which was composed of both a sensing EGFET and a reference EGFET.

2. Experimental Methods

The p-type (100) SOI wafer with a resistivity of 10-Ω·cm top silicon layer was used as a substrate. The thickness of top silicon and buried oxide (BOX) layer is 100 and 750 nm, respectively. After standard RCA cleaning processes for the surface of SOI substrate, a 170-nm-thick phosphorus-doped polycrystalline silicon (poly-Si) layer was deposited at source/drain (S/D) regions through low-pressure chemical vapor deposition (LPCVD). And then, a SiO_2 layer with a thickness of 10 nm was grown by thermal oxidation as a top gate oxide. To reduce the defect density and improve the electrical properties of the devices, rapid thermal annealing (RTA) at 850 ℃ for 30 sec in N_2/O_2 gas ambient was conducted. After that, Al gate electrode of 150-nm-thick was formed using e-beam evaporator. Finally, a forming gas annealing at 450 ℃ for 30 min in 2% H_2/N_2 ambient was performed to remove the dangling bonds between gate dielectric and channel. Both channel length and width were 10 μm. The fabricated SOI-MOSFET was applied for FET part of EGFETs. Meanwhile, the tin dioxide (SnO_2) film was used as a sensing membrane for the sensing part of EGFETs. It was deposited by RF magnetron sputtering with a thickness of 50 nm. A schematic representation of fabricated EGFETs, with SG and DG operation mode, was shown in Fig. 1. Fig. 2 shows a schematic diagram of differential-measurements biosensor using two EGFETs. The drain current versus gate voltage (I_D-V_G) curves for the various *p*H solutions were measured by using an Agilent HP4156B high-precision semiconductor parameter analyzer, and all measurements were carried out in a dark box, to avoid interferences from light and electrical noise.

3. Results and Discussion

Fig. 3 shows the transfer (I_D-V_G) and output (I_D-V_D) characteristic curves of the SOI-MOSFET. The fabricated SOI-MOSFETs exhibited excellent electrical characteristics including a high on/off current ratio of 2.7×10^{10} and a good subthreshold swing (SS) of 63 mV/dec.

Fig. 4 shows the transfer curves of (a) SG and (b) DG EGFETs in different *p*H buffer solutions. The threshold voltage (V_{th}) shift according to variation of *p*H solution from *p*H 3 to *p*H 10 showed a tendency. As a result, the sensitivity of DG EGFETs exhibited 2019.54 mV/pH, which is much higher value than that of SG EGFETs (59.74 mV/pH). From this result, we could confirm that the DG EGFETs were working properly.

Fig. 5 shows the threshold voltage shift by the reactions between LUSH and ethanol in (a) SG and (b) DG EGFETs based on differential-measurement system. At first, we injected the LUSH in sensing FET, and PBS 0.01X in reference FET, respectively. And then, ethanol with different concentration (0.001, 0.01, 0.1, and 1 %) was injected into the each chamber in order of increasing concentration. As a result, in both SG and DG EGFETs, the V_{th} in sensing FET was consistently shifted with concentration increment of ethanol, whereas V_{th} in the reference FET was almost not shifted. It means that LUSH reacts to the ethanol and to confirm the reaction, through the electrical signals using FET devices, is possible. Meanwhile, in case of the SG EGFETs, the sensitivity for the reaction exhibited very low value, which revealed average 1.99 mV per step. In contrast, the sensitivity of DG EGFETs showed average 129.45 mV per step, which was an amplified value 60 times larger than that of SG EGFETs. Consequentially, we detected the reaction between LUSH and ethanol through the enhanced electrical signal.

4. Conclusions

We fabricated the SG and DG EGFETs with a differential-measurement system, and evaluated the reactions between LUSH and ethanol. As a result, we firstly detected the reactions between LUSH and ethanol, through the electrical signal using FET devices. Also, we significantly enhanced the sensitivity of reactions using the DG EGFETs. Therefore, it is expected that the DG EGFETs with differential-measurement system will be a promising biosensor as a novel diagnostic, which can detect the chemosensory response between materials.

Acknowledgements

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References

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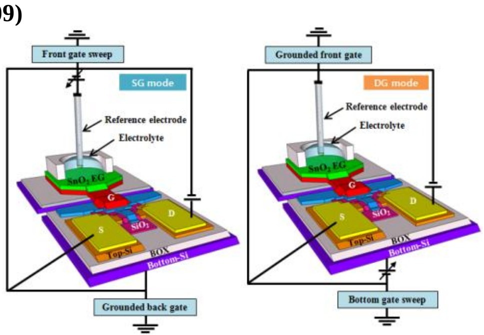

Fig. 1 Schematic representation of fabricated EGFETs with SG and DG operation mode, respectively

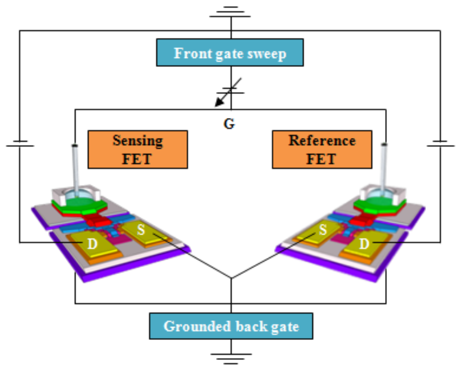

Fig. 2 Schematic diagram of differential-measurement system using two EGFETs (in SG operation mode)

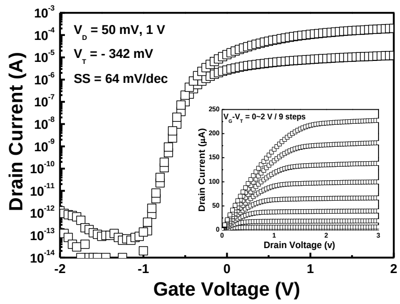

Fig. 3 Transfer and output characteristic curves of the SOI-MOSFETs

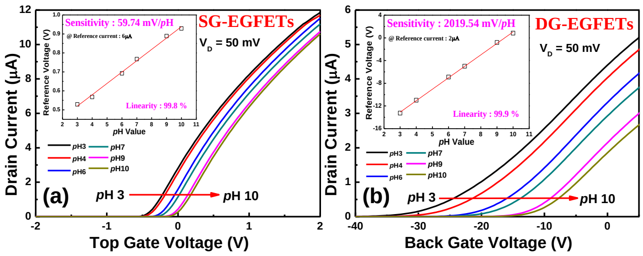

Fig. 4 I_D-V_G curves response of (a) SG and (b) DG EGFETs in different *p*H buffer solutions

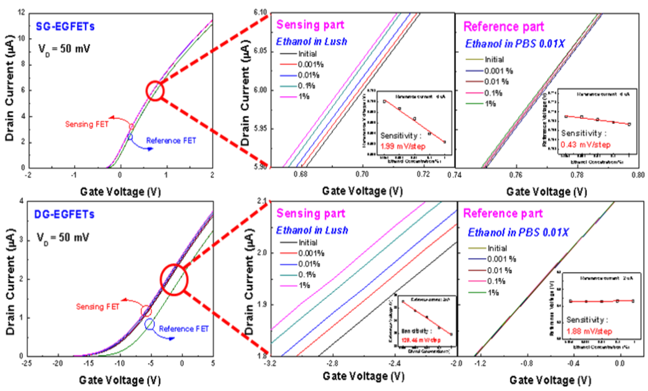

Fig. 5 Threshold voltage shift by the reaction between LUSH and ethanol in (a) SG and (b) DG EGFETs based on differential-measurement system