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A study of olfactory signal sensing with FET biosensor

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1. Introduction

The human olfactory system was discovered by Buck and Axel in 1991 [1]. They found that mammalian olfactory system can detect and discriminate a great number of diverse odorant molecules. Specific odorant molecules bind with inherent olfactory receptor and this binding leads to flux of intracellular and/or extracellular ion through ion channel. Subsequently, changed ion concentration induces an action potential of olfactory cell and it can be detected by various transducers with electronic device.

Ion sensitive field effect transistors (ISFETs) have been used to chemical sensor since it was developed by Bergveld in 1970 [2]. Source-drain sensing current of ISFET greatly depends on gate voltages. Therefore, gate potential change induced by action potential of olfactory cell cultured onto the gate region sensitively modulates sensing currents.

In this study, we fabricated FETs with recessed channel for biosensor and detected signal change with living olfactory neural cells.

2. Experimental

Fig.1 shows the fabrication procedure of a FET biosensor including recessed channel. A p-type Si (100) with oxidized of 300 nm wafer was used to starting material. After define active region, highly conductive in-situ phosphorus-doped poly-Si of 100 nm was deposited by LPCVD for S/D junction. Recessed channel of 30 nm depth was formed by reactive ion etch in CF_4 ambient. The device with recessed channel has advantages in terms of fabrication process, such as structure advantageous to cell seeding, and ability to use of high-k gate dielectric (because of gate last process). To protect the device from aqueous and moist measurement environment such as alkaline or acidic solution, cell culture media, electrolyte, etc, SiO_2 of 300 nm was deposited by sputtering method. Next, 10 nm SiO_2 for gate oxide was deposited by sputtering method. Annealing process for S/D activation was performed at 850℃ for 30 seconds. Al was deposited by e-beam evaporator to form metal gate electrode and contact pad. The FETs were heat treated at 450℃ in N_2:H_2 (98%:2%) mixed gas ambient for 30 minutes. FETs were packaged by polydimethylsiloxane (PDMS) except channel region. Fig. 2 shows the practical device and optical microscope images of fabricated biosensor with 4x4 FET array.

Olfactory neural cells from Sprague Dawley rat pups (day 0.5~1) were cultured onto the channel region of FETs and we measured the signal changes.

The current-voltage (I-V) characteristics of the fabricated FETs were measured using a semiconductor parameter analyzer.

3. Results and discussion

Fig. 3 shows I-V characteristics of the fabricated FETs. As shown in Fig. 3, the device shows excellent transfer characteristics such as low leakage current ($<10^{-12}$ A), a steep subthreshold slop (74 mV/dec), and a high on/off current ratio ($\sim10^8$).

Olfactory living cells response with several tens of action potential through ion channel caused by odorant. Hence, we test the response signal as change the input gate potential of 0.1 V and constant drain voltage of 1 V. As shown in Fig. 4, the FET showed well response to pseudo action potential.

Fig. 5 shows current response of FET for various pH solutions from 7 to 4 at drain voltage of 1 V. The FET revealed certain current changes upon its exposure to different hydrogen concentrations.

In Fig. 6, the drain current of bioFET with olfactory neural cell shows a difference between growth media used for cell culture, Dimethylsulfoxide (DMSO), ammonium, and methylene chloride aqueous solution in constant source-drain voltage because olfactory neural cell onto gate region reacts to aqueous solution and induces the action potential.

Furthermore, we cultured human embryonic kidney 293 cells (HEK-293 cells) onto Si and SiO_2 substrates with photoresist pattern. As the shown in Fig. 7, HEK-293 cell cultured in localized rectangular pattern without any immobilization processes. Therefore, we expect that these selective culture properties can be used to next experiments usefully.

4. Conclusions

BioFETs with recessed channel were fabricated and investigated. The fabricated bioFETs showed excellent transfer characteristics and response to reaction of living olfactory neural cell. Therefore, we confirmed the feasibility of bioFET used in this study for olfactory sensor applications.

Acknowledgement

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References

[1] Lind Buck and Richard Axel, cell, vol.65, (1991), 175.
[2] P. Bergveld, IEEE Trans.Biomed. Eng. vol. 17, (1970), 70.

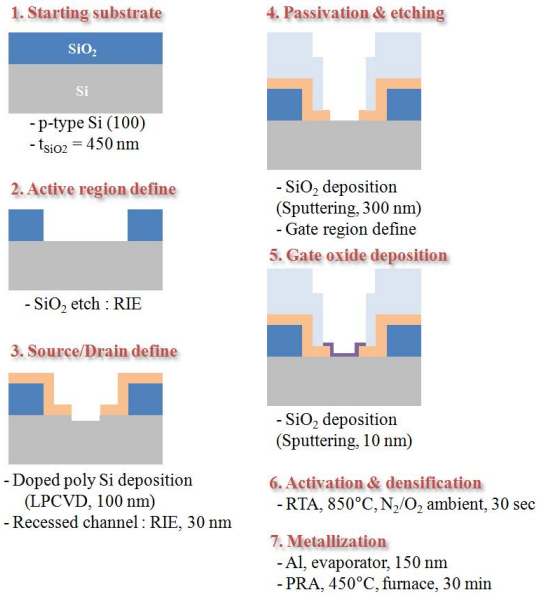

Fig. 1. Fabrication procedure of FET biosensor

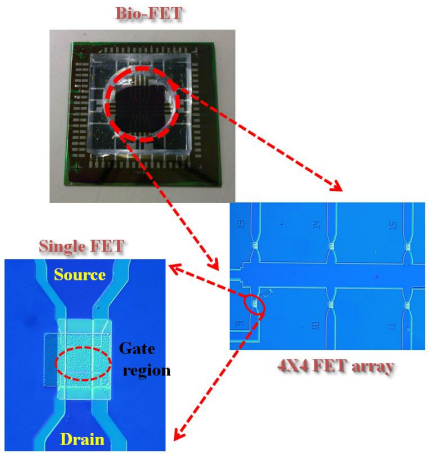

Fig. 2. Practical device image and optical microscope images of fabricated biosensor with 4x4 FET array.

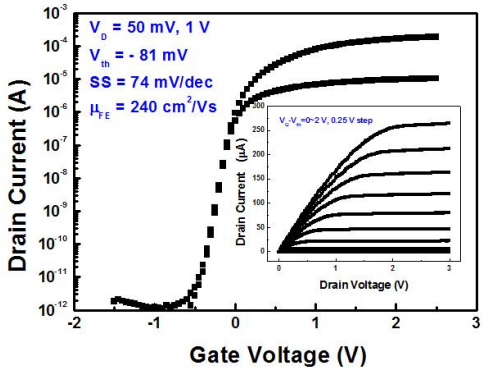

Fig. 3. Drain current versus gate voltage (I_D-V_G) characteristic. L/W = 10/10 μm. (insert is I_D-V_D characteristic)

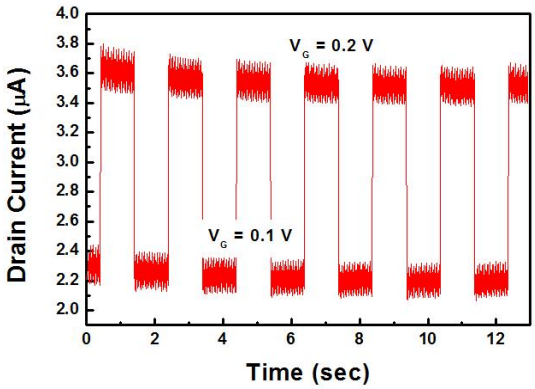

Fig. 4. Drain current response of FETs as gate potential change.

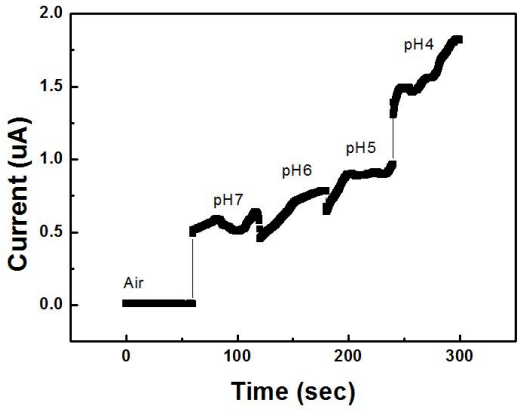

Fig. 5. Current response of FETs with varying (7~4) pH solutions..

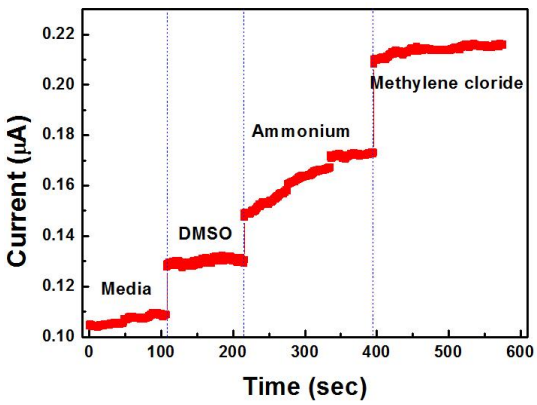

Fig. 6. Dynamic response of olfactory neural cell cultured FET biosensor with various aqueous solutions.

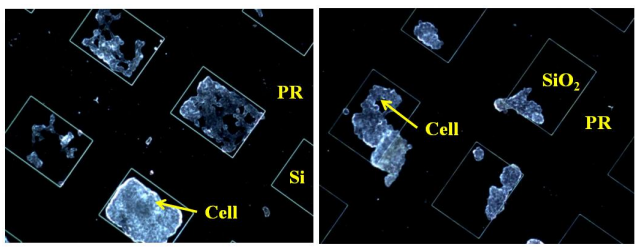

Fig. 7. Optical microscope images of HEK-293 cells cultured onto (left) Si and (right) SiO_2 substrate. The cells were cultured in rectangular pattern formed by lithography process using photoresist (PR), precisely.