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FET-based Biosensors for Detection of Biomolecules

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1. Introduction

There have been considerable efforts to detect biomolecules with the progress of life science and measurement techniques. Recent discoveries and new techniques are gradually changing our knowledge of living structures and suggest new possibilities to explore and characterize biomolecules. Among the various types of biosensors, field-effect transistor (FET)-based biosensors which are fabricated by the semiconductor integrated circuit technology, have attracted considerable attention because of their many advantages in terms of miniaturization, standardization, mass-production and its suitable configuration for smart sensors in which both the sensors and measurement circuits are integrated in the same chip. They are especially suitable for the detection of charged biomolecules and showed some promising experimental results for DNA, proteins, lipids and toxins [1-5]. In this paper, current status and operational principles of the FET-based biosensors, especially of the MOSFET-based biosensors, are described.

2. FET-based Biosensor

FET-based biosensors are originated from the ion-sensitive field-effect transistor (ISFET) which was invented by Bergveld in 1970 [6]. The physical structure of the FET-based biosensors for detecting biomolecules is very similar to that of a MOSFET and the operating principle can be explained on the basis of the interaction of charged biomolecules and MOSFET. Figure 1 shows the schematic structures of the conventional MOSFET and the MOSFET-based biosensor. The normal metal or polysilicon gate electrode of the MOSFET is replaced by the reference electrode in an electrolyte solution and Au thin film which has a chemical affinity with thiol on top of the gate insulator. A gate voltage is applied to the gate insulator via the reference electrode and the electrolyte solution for the proper operation of the biosensor. An electrochemical potential is then developed at the surface of Au with the binding of self-assembled monolayer (SAM) of thiol and biomolecules. In addition, variation of the capacitance is generated by the binding of biomolecules. These results can be measured as a shift in drain current or threshold voltage.

3. Vertical MOSFET-based Biosensor

Most of the FET-based biosensors should be operated in liquid solutions and instruments for measuring steadily decreasing sample volumes at less expense are being required. In addition, micro-fluidic prototype devices and systems have been developed for economic and portable diagnostic applications. In order to integrate both FET-based biosensors and micro-fluidic channels on the same chip, vertical MOSFETs for detection of biomolecular charges are formed in the Si micro-fluidic channel [7]. Figure 2 shows the schematic structure of the vertical MOSFET embodied in the convex corner of the Si micro-fluidic channel. Figure 3 exhibits the real-time variation of the drain current according to the thiol injection. This result shows that the vertical MOSFET exhibits reasonable electrical characteristics and might be useful for detecting charged biomolecules in a fluidic channel.

4. Extended-gate MOSFET-based biosensor

In order to alleviate the electrical isolation problem between the MOSFET-based sensor and the chemical solution, extended-gate structure is proposed [8]. In this configuration, a chemically and biologically sensitive membrane is deposited on the end of a signal line extended from the MOSFET gate electrode and the MOSFET itself is separated from the solution. The extended-gate structure has many advantages such as insensitivity to temperature and ambient light, simple method of passivation and packaging, flexibility of the shape of the extended gate. Figure 4 shows the schematic structure of the extended-gate MOSFET-based biosensor in which an extended gate is formed at the bottom of the Si micro-fluidic channel. Figure 5 exhibits electrical charactertistics of the biosensor as a fuction of the interactions among SAM, streptavidin and biotin.

5. Conclusions

Various types of FET-based biosensors have shown promising results for detection of biomolecules. Although there still exist some inherent problems for practical applications, future progress in semiconductor and MEMS technology might enable the FET-based biosensors to become a useful component in lab-on-a-chip and micro total analysis system.

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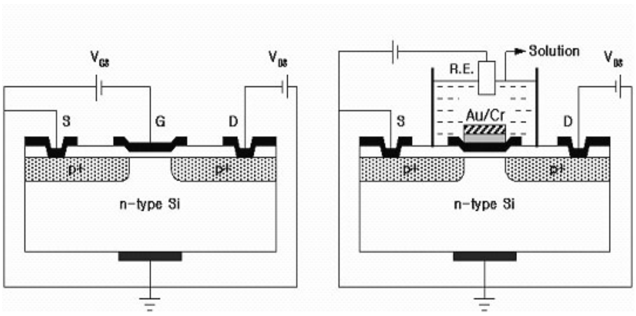

(a) (b)

Fig. 1 Schematic structures of (a) the conventiomal MOSFET and (b) the MOSFET-based biosensor.

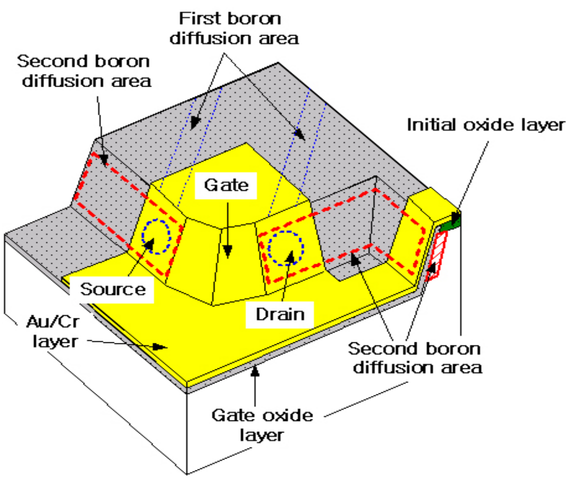

Fig. 2 Schematic structure of the vertical MOSFET embodied in the convex corner of the Si micro-fluidic channel.

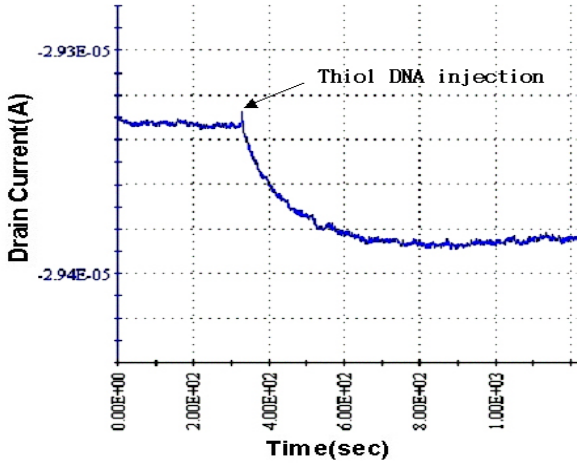

Fig. 3 Real-time variation of the drain current according to thiol injection.

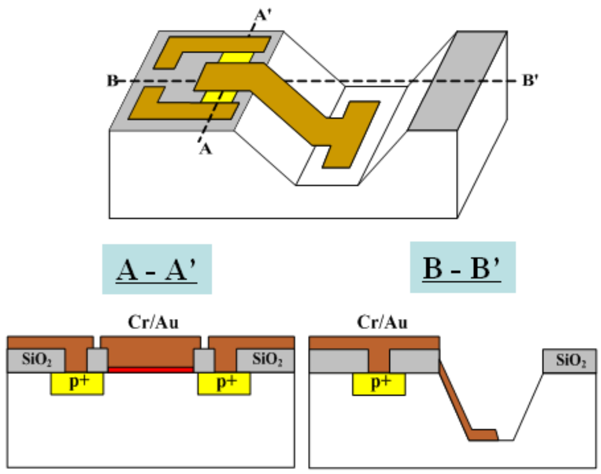

Fig. 4 Schematic structure of the extended-gate MOSFET-based biosensor.

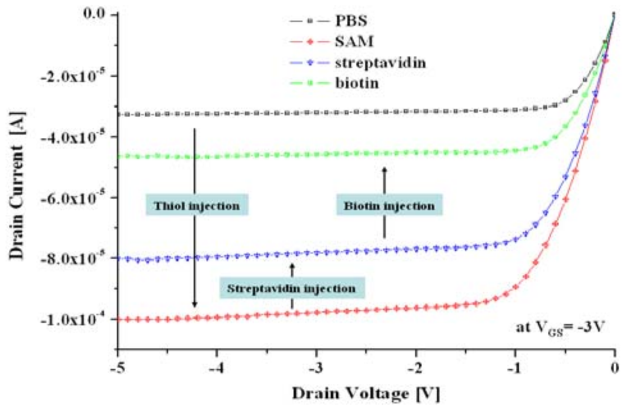

Fig. 5 Electrical characteristics of the extended-gate MOSFET -based biosensor as a function of the interactions among SAM, streptavidin and biotin.