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Highly Sensitive Biosensor Platform Based on Substrate Bias Extended-Gate Field-Effect Transistor

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Summary:
A novel electrical protocol featuring substrate bias modification is applied to extended-gate field-effect transistors (EGFETs) to enhance the pH sensitivity beyond the Nernst limit. The sensitivity enhancement driven by the body effect characteristics of the p-channel metal-oxide-semiconductor field-effect transistor (MOSFET), which serves as the transducer. As proof-of-concept in the biosensor application, the proposed method achieved sensitivity around 320 mV/dec for DNA detection, 16 times higher than the conventional gate-bias configuration which yielded sensitivity around 20 mV/dec.

Keywords: Biosensor, EGFET, DNA, body effect, sensitivity

Introduction

Theoretically, field-effect transistor-based (FET-based) sensors obey the Nernst equation which shows that the maximum pH sensitivity that can be achieved is around 59 mV/pH at room temperature [1]. However, sensitivity enhancement of pH sensors to surpass the Nernst limit is possible on the transducer side, which is important in biosensor that requires detection of small potential changes.

A different structure of FET such as tunnel FET (TFET) is reported by Dwivedi et al. to enhance the sensitivity which utilizes the property of band-to-band tunneling phenomenon in the TFET to yield sensitivity up to 180 mV/pH [2]. Another method that has been reported by several researchers is the use of double-gates FET or even multiple-gates FET. This method was first reported by Spijkman et al. in 2010 that shows the possibility of sensitivity that could be achieved up to 2.25 V/pH [3]. In this type of method, the key to sensitivity enhancement is the ratio of the capacitive coupling between the top oxide and the bottom oxide of each gate, respectively. With the same concept, Cho et al. reported the use of triple-gates FET sensor could reach 2.36 V/pH [4]. These reported methods are effective to enhance the sensitivity of FET-based sensors from the transducer side, with the requirement of a customized transducer. However, the complex fabrication of the customized transducer and the requirement of a semiconductor development facility could hinder the replication of similar methods in a limited environment.

Substrate bias EGFET

In this study, we utilized body effect characteristics of the commercial p-channel MOSFET (PMOS) that is used as transducer in an extended-gate field-effect transistor (EGFET) configuration. The extended gate was fabricated by sputtered TiN on indium tin oxide (ITO)/glass substrate. In a long channel device, typically, the body effect of PMOS is smaller than that of the n-channel MOSFET (NMOS) counterpart. Smaller body effect means higher V_{BS} is required to get a significant deviation of threshold voltage (V_{th}). Since V_{th} determines the activation of the channel of the MOSFET, the shifting of V_{th} by the body effect can be understood as the effect of V_B on the channel activation. The small body effect means the less effectiveness of V_B to control the channel activation.

Unlike conventional EGFET that uses gate voltage (V_G) to control the channel, in this proposed method, V_B is used to control the activation of the channel. The sensing membrane is still connected to the gate terminal of the MOSFET; thus, the surface potential still follows the Nernst limit. The reference electrode is then biased with a constant voltage that exceeds the initial V_{th} to induce an initial generation of the channel. The V_B is then used to turn off the channel utilizing the body effect, since at one point the V_G will be lower than the shifted-V_{th}. Owing to the small body effect of PMOS, high V_B is required to completely close the channel of the MOSFET, which leads to high sensitivity enhancement.

Results

Fig. 1 shows a quick pH measurement test to ensure the sensor worked properly prior to the biosensor functionalization. Both substrate bias and gate bias configurations used the same PMOS transistor. Our preliminary study showed that biosensor application is feasible with a DNA hybridization technique that yielded sensitivity around 320 mV/dec compared to the sensitivity around 20 mV/dec of the conventional EGFET, as can be seen in Fig. 2. Both pH measurement and DNA detection showed the substrate bias is much more sensitive, more than 16 times that of the conventional gate bias. Fig. 3 and Fig. 4 show the I-V curves of DNA detection using substrate bias and gate bias, respectively.

The proposed method offers an efficient sensitivity enhancement method for FET-based sensors as the enhancement can be made even with the available commercial MOSFETs.

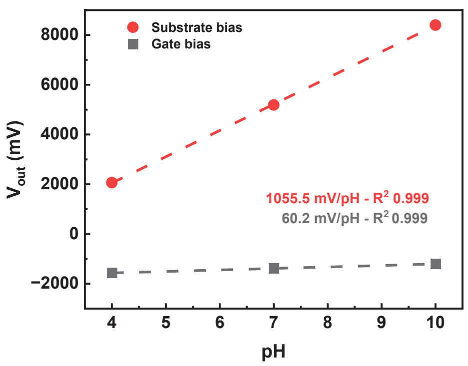

Fig. 1. pH measurements of TiN EGFET with gate bias or substrate bias configuration.

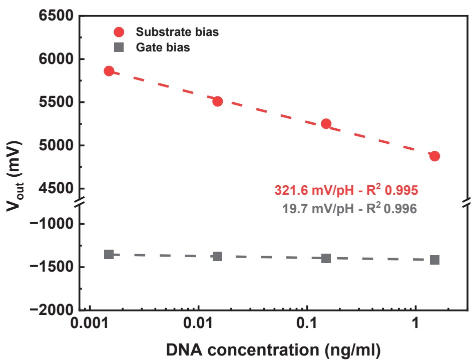

Fig. 2. DNA detection test of TiN EGFET with gate bias or substrate bias configuration.

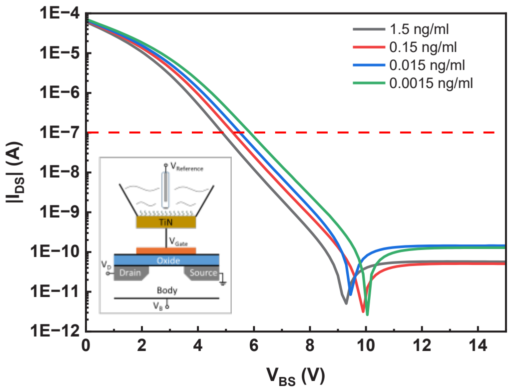

Fig. 3. I-V curve of DNA detection with substrate bias configuration of TiN EGFET.

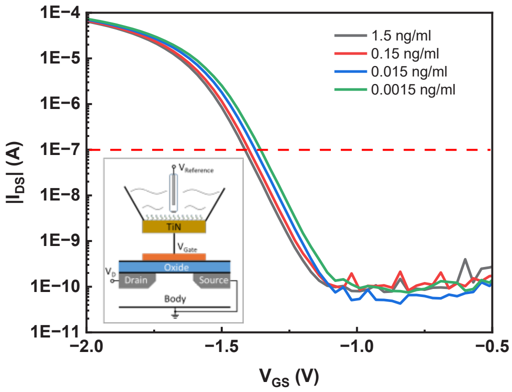

Fig. 4. I-V curve of DNA detection with gate bias configuration of TiN EGFET.

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