LABEL-FREE ELECTRICAL DETECTION OF PSA BY A NANOGAP FIELD EFFECT TRANSISTOR

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ABSTRACT

This study demonstrates the label-free electrical detection of prostate specific antigen (PSA) using a field effect transistor (FET) device with a molecular-sized vertical nanogap. The threshold voltage (V_T) of the device is changed through PSA binding in the nanogap. It is observed that a higher concentration of PSA shows a larger V_T shift.

KEYWORDS: Nanogap, field effect transistor, prostate specific antigen, label-free electrical detection

INTRODUCTION

Due to high sensitivity arising from nanoscale dimension which is comparable to size of a molecule, nano-structured devices are being studied for use as sensors of biomolecules [1]. Recently, the feasibility of a prototype of a nanogap field effect transistor (FET) as a biosensor was demonstrated with the specific binding of biotin-streptavidin [2]. This paper primarily focuses on label-free electrical detection of PSA based on V_T changes through selective PSA binding in the vertical nanogap .

DEVICE STRUCTURE

Figure 1 shows a cross-sectional view of the proposed FET for PSA detection. It consists of a p-type silicon channel separated from a suspended polysilicon gate standing on gate dielectrics. Anti-PSA is immobilized on a self-assembled monolayer (SAM) that is formed on a native oxide of the suspended polysilicon gate. PSA is then specifically bound to anti-PSA. PSA binding increases the vertical electric field due to the increased dielectric constant that results from the filling of the nanogap. Consequently, V_T decreases and specific binding of PSA can be electrically detected by measuring the change of the V_T value without the need for labeling sequences.

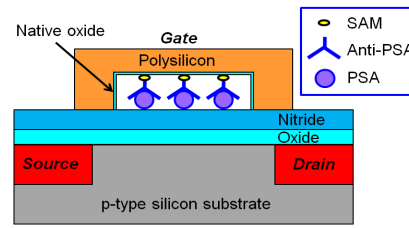

Figure 1: A cross-sectional view of the proposed FET with a vertical nanogap. The nanogap is filled with PSA and anti-PSA, causing a shift of the threshold voltage.

Figure 2 shows the fabrication process flow. A p-type (100) bulk silicon wafer is used as a substrate, and source/drain implantation is performed with a designed mask. To form gate dielectric layers, an oxide layer is thermally grown and a nitride layer is deposited by chemical vapor deposition. After subsequent deposition and patterning of a sacrificial phosphosilicate glass (PSG) layer, a polysilicon gate is

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formed. A film thickness of the PSG is tuned for a target molecule size. The nitride layer is used to protect the gate oxide from possible damage by the buffered oxide etchant employed for removal of the PSG sacrificial layer.

Images of the fabricated device are shown in Figure 3. In the optical microscope image, the PSG sacrificial layer is shown beneath the suspended polysilicon gate. The SEM image shows a vertical nanogap that is 24nm in height. The nanogap height should correspond to the deposited PSG thickness, but it is enlarged because a 4nm nitride is additionally etched during lateral etching of the PSG to create a wide nanogap (>1μm).

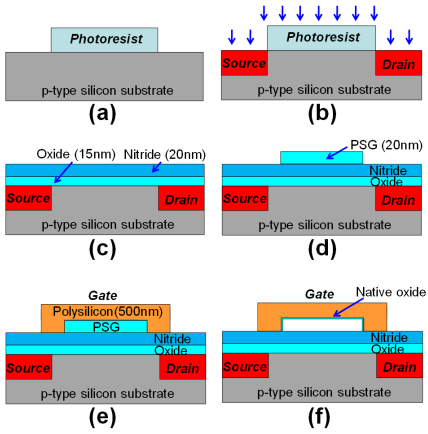

Figure 2: The process flow. (a) Photoresist is coated. (b) A source/drain junction is formed on a p-type silicon substrate by ion implantation. (c) A thermal oxide (15nm) is grown and a nitride (20nm) is sequentially deposited. (d) A 20nm thick phosphosilicate glass (PSG) sacrificial layer is deposited and patterned. (e) N+ in-situ doped polysilicon (500nm) is deposited and delineated. (f) The PSG sacrificial layer is removed by buffered oxide etchant.

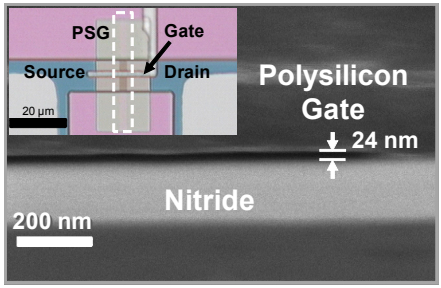

Figure 3: Images of the fabricated device. The inset shows the top view of the device taken with an optical microscope. The dotted line indicates the PSG sacrificial layer. The background SEM image shows that the vertical nanogap is properly formed.

EXPERIMENTAL RESULTS

Transfer characteristics (I_D-V_G curves) are shown in Figure 4. After anti-PSA immobilization, V_T decreases by 0.4V. Before the immobilization of anti-PSA, the device is dipped into 1 wt% of trimethoxysilane aldehyde in ethanol for two hours, washed in ethanol, and heated at 120°C for 30 min to form a SAM [3]. The device is then placed into a 100μg/ml solution of anti-PSA for four hours and washed in deionized water. An additional large V_T shift of 0.5V is measured after dipping the device into a 100μg/ml solution of PSA and washing, as the specific binding of anti-PSA and PSA increases the dielectric constant in the nanogap. By comparing V_T values at each step, the specific binding of anti-PSA to PSA can be electrically detected without an extra labeling process. Figures 5 (a) and (b) show AFM images of the silicon dioxide surface before PSA binding (no chemical treatment) and after PSA binding, respectively. Figure 6 shows V_T shifts after PSA binding according to various PSA concentrations. A larger shift of V_T is observed with a higher concentration of PSA.

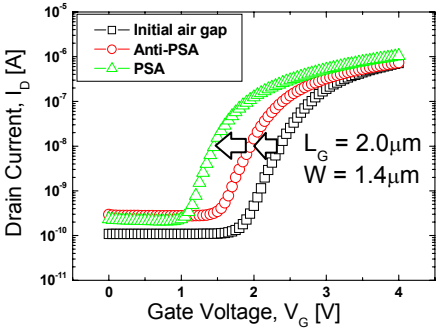

Figure 4: Transfer characteristics (I_D-V_G curves) measured by a semiconductor parameter analyzer (HP4156C). 50mV was applied to the drain. The concentration of Anti-PSA and PSA was 100μg/ml.

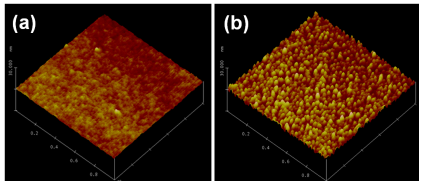

Figure 5: AFM images (a) before the chemical treatment and (b) after PSA binding on a silicon dioxide surface

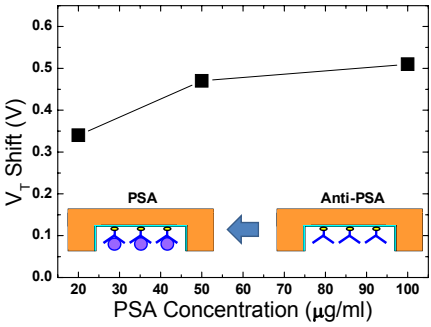

Figure 6: Dependency of the V_T shift on the PSA concentration

CONCLUSIONS

This study presents a nanogap FET that detects PSA using a label-free electrical method. PSA was successfully detected by measuring the V_T shift after filling the nanogap through PSA binding. This nanogap FET can be used for electrical detections of various types of biomolecules without the need for a labeling process.

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