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# Comparison of Top gate Structures for Carbon Nanotube Field Effect Transistor Biosensor

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## 1. Introduction

Developing compact and simple biosensors that can perform real-time measurements is very important for home medical care in distant places. A carbon nanotube field-effect transistor (CNT-FET) should be able to detect living biological molecules with high sensitivity because its electron capacitance is very small. We detected proteins by using a top gate CNT-FET [1]. The proteins (antigens) react with antibodies on the top gate of the CNT-FET biosensor, and the biosensor detects the electron charges of the antigens on the top gate. Therefore, the structure of the top gate significantly affects the performance of the sensor. We prepared a CNT-FET biosensor without a metal top gate and compared its performance to that of one with a top gate.

## 2. Experiment

Silicon nitride was used as an insulator in the sample CNT-FET. The silicon nitride layer was covered with a waterproof resist. For the CNT-FET without the metal top gate, the area above the CNT channel was not covered with a waterproof resist. We used pig serum albumin (PSA) and anti pig serum albumin (a-PSA) for the measurement, where PSA and a-PSA are an antigen and a corresponding antibody. The a-PSA was physically adsorbed onto the silicon nitride of the CNT-FET, which is referred to as the metal gateless PSA sensor (See figure 1(a).). To determine what effect the metal top gate had on the performance of the sensor, we also prepared a CNT-FET with metal top gate. The a-PSA was physically adsorbed onto the metal top gate of CNT-FET, which is referred to as the PSA sensor, with metal gate (See figure 1(b).). For the measurement, a silicone rubber wall was placed on the PSA sensor, where a solution of Tris buffer (pH 8.0) containing PSA was poured. The dependence of the drain current on the PSA concentration was measured.

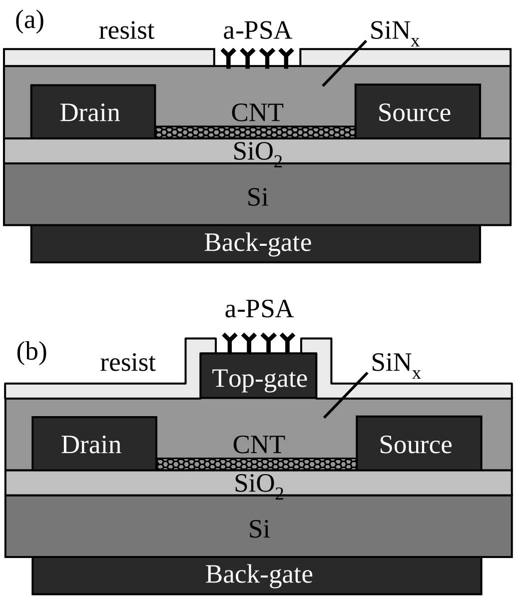


Figure 1. Structure of PSA biosensor.
(a) Metal gateless PSA sensor.
(b) PSA sensor with metal gate.

## 3. Results and Discussion

Figure 2(a) shows the drain current-top gate voltage curve of the metal gateless PSA sensor onto which the Tris buffer without PSA was poured. The metal gateless PSA sensor displayed an n-type property because the drain current increased when the top gate voltage was swept in the positive direction. At a drain voltage of +1 V, a top gate voltage of +1 V, and a back gate voltage of +5 V, the transconductance, $g_m$, was 163.7 nS. When Tris buffer containing PSA was poured onto the metal gateless PSA sensor at $V_{TG}$ = +1 V, the drain current decreased compared to when Tris buffer without PSA test solution was used. The decrease in the drain current was obtained as $\Delta I_D$. The dependence of $\Delta I_D$ on PSA concentration is shown in figure 2(b). This result is consistent with the Langmuir adsorption isotherm. The logarithm of the equilibrium constant, log $K_{eq}$, was obtained as 8.09 from the Langmuir fitting. We demonstrated that the CNT-FET biosensor we developed can detect protein.

Next, we determined the properties of the PSA sensor with metal top gate. We prepared the CNT-FET identical to the one we used to measure the metal gateless PSA sensor, and we placed a metal top gate was placed on it. The results are shown in figure 3. At a drain voltage of +1 V, a top gate voltage of +1 V, and a back gate voltage of +5 V, the transconductance, $g_m$, was 62.0 nS. The logarithm of the equilibrium constant, log $K_{eq}$, was obtained as 7.93.

Given that the sensitivity limit of the PSA concentration was the same as that when the $\Delta I_D$ was 1 nA, that of the metal gateless PSA sensor was 0.1 nM and that of the PSA sensor with metal gate was 0.7 nM. In conclusion, we have improved the performance of the CNT-FET biosensor by using a CNT-FET without a metal top gate.

## References


[1] M. Abe, K. Murata, A. Kojima, Y. Ifuku, M. Shimizu, T. Ataka, and K. Matsumoto, *J. Phys. Chem. C*, In press.


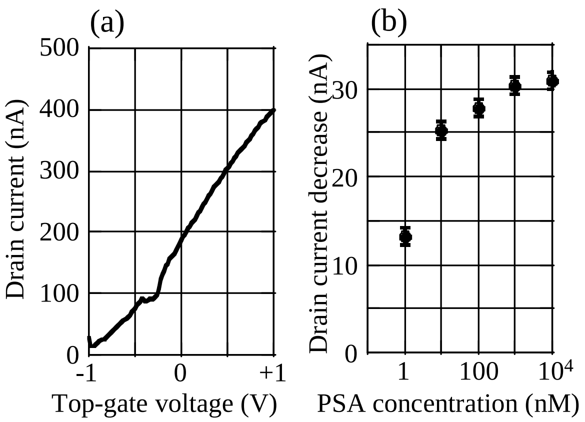


Figure 2. Properties of metal gateless PSA sensor.
(a) Drain current-Top gate voltage curve.
($V_D$ = +1 V, $V_{TG}$ = +1 V, $V_{BG}$ = +5 V)
(b) Dependence of drain current decrease on PSA concentration.

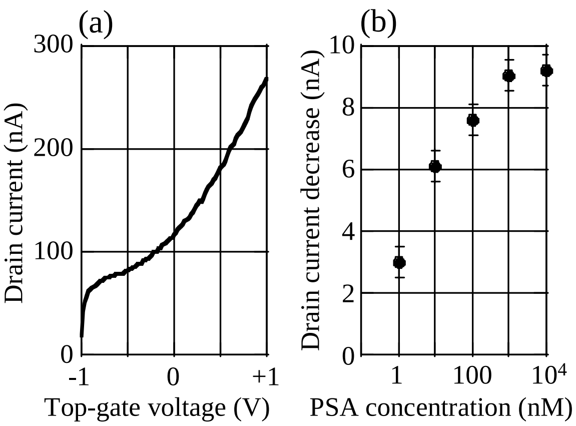


Figure 3. Properties of PSA sensor with metal gate.
(a) Drain current-Top gate voltage curve.
($V_D$ = +1 V, $V_{TG}$ = +1 V, $V_{BG}$ = +5 V)
(b) Dependence of drain current decrease on PSA concentration.