Extended Abstracts of the 2016 International Conference on Solid State Devices and Materials, Tsukuba, 2016, pp379-380

H-2-05

Development of paper-based transistor toward direct detection from micro biological fluids

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Abstract

Paper-based transistor was developed by combination of cellulose/Au nano particle (AuNP) with extended gate field-effect transistor (FET). Mercaptophenylboronic acid (MPBA) was modified on the surface of AuNP as self-assembled monolayers (SAMs) and chemically bound with cellulose by diol binding between hydroxyl groups of cellulose and those of boronic acid. MPBA-SAM modified AuNP was aggregated with each other by forming boroxine which was condensed of three boronic acids. Boroxinated-AuNP was observed using absorption spectrum and zeta potential analysis.

Boroxinated-AuNP solution was absorbed in cellulose consisted paper such as a paper electrode, and put on the Au extended-gate metal-oxide-semiconductor (MOS) FET. After drying paper, glucose detection was tested by absorption of each concentration of glucose solution. In the result, gate surface potential was increased as the glucose concentration was raised when the source-drain current adjusted as constant.

1. Introduction

Non-invasive as free for blood sampling and simplified glucose detection is needed for diabetes reserve and patient toward medical diagnostic for quality of life (QOL) and preventive care for reduction of medical expense. Although the body fluids without blood can be mentioned as tears, sweat, saliva, and interstitial fluid, it was difficult for determination of glucose concentration by enzymatic method in existence because the volume of these samples was too small and low concentration. From these background, our group has been studied about field-effect transistor (FET) which is able to capture the trace ion changes at gate surface for sensitive biosensor with detecting small organic molecules or ions [1-4]. Recently, it was reported about highly sensitive sensing using phenylboronic acid (PBA) modified gate FET [5]. In this study, applying the principle of PBA modified FET, we fabricated and fundamentally evaluated the paper-based transistor which was able to absorb small amount of biological fluid to the gate electrode as microfluidics.

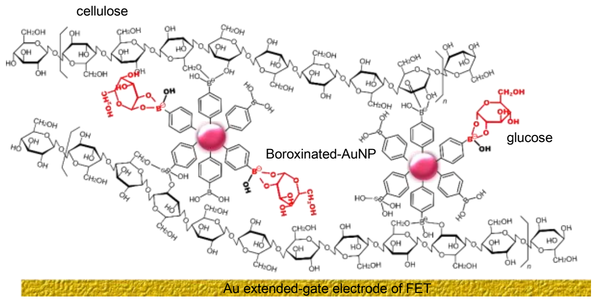

Fig. 1 The diagram of cellulose and boroxinated-AuNP conjugate at the Au gate surface of paper-based transistor.

2. Fabrication and characterization of paper-based transistor

Extended-gate FET which was separated gate electrode from FET main unit was used as the detection device of paper-based transistor and gold was selected as the gate electrode. In addition, change in the charges owing to the binding the glucose recognition molecule with glucose were converted into an electric signal by designing the glucose detection device on the surface of gold electrode. In particular, saccharides recognition element was fabricated by placing the paper impregnated with the solution of AuNP whose surface was modified with 4-mercaptophenylboronic acid (MPBA) self-assembled monolayers (SAMs), and the negatively charge changes derived from specific diol binding of PBA and glucose was detected as gate surface potential shift using FET (Fig. 1). Measurement of glucose by the paper-based transistor was carried out by monitoring the gate surface potential changes of the gate electrode using a real-time measurement system at a gate voltage (V_G) of 0 V and a source-drain current (I_{SD}) of 700 μA.

First of all, when PBA-SAM was introduced to the surface of AuNP, the reactive solution was turned into red color to gray color and the gray aggregated AuNP was partially precipitated (Fig. 2A). It was also supported by the results of absorption spectrum and zeta potential analysis. The peak absorbance of localized plasmonic spectrum of AuNP (534 nm, calculated as 40-50 nm diameter of AuNP) was obviously decreased after SAM modification. Zeta potential of AuNP was increased compared with non-modified AuNP indicating that the surface of AuNP was electrically neutralized by the PBA modification (Fig. 2B). From these results, it was anticipated that AuNPs were aggregated because the modified PBAs at the surface of AuNP formed boroxine that three boronic acids bound by di-ester binding with each other [6].

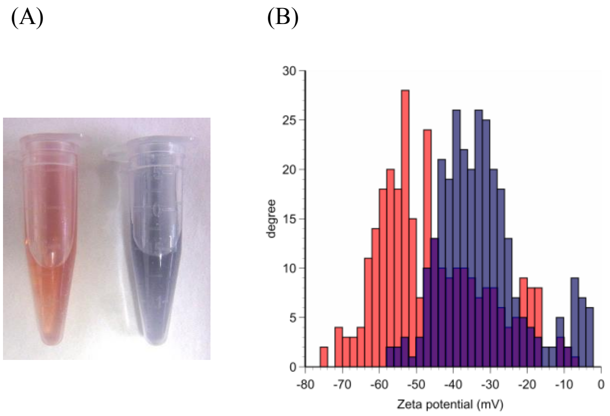

Fig. 2 Changes in AuNP with PBA-SAM modification.
(A: color changes by PBA-SAM treatment. left; non-modified AuNP, right; PBA-SAM modified AuNP.
B: zeta-potential distribution of non- and PBA-SAM modified AuNP. Red; non-modified AuNP, blue; PBA-SAM modified AuNP)

Using the boroxinated-AuNPs, glucose detection was tested by the paper-based transistor which was combined Au gate electrode with boroxinated-AuNP impregnated paper. As a result, gate surface potential shift was observed from ca. 10 μM addition of glucose concentration while that of the non-PBA modified AuNP combined paper-based transistor was not changed at all. Thus, it was suggested the possibility of quantifying the diluted glucose solution from

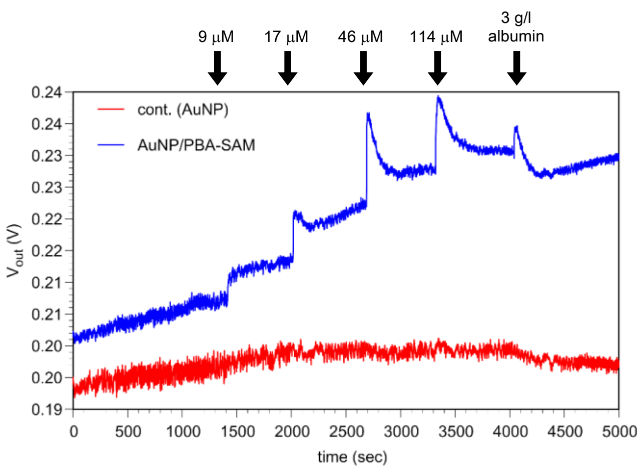

Fig. 3 Real-time monitoring of gate surface potential in paper-based transistor.
(red: gate surface potential changes in paper-based transistor containing non-modified AuNP, blue: gate surface potential changes in paper-based transistor containing PBA-SAM modified AuNP. Arrows indicate glucose addition in each concentration.)

small amount of body fluid using the paper-based transistor. In the conference, we would like to discuss about the relation between the electrochemical phenomenon derived from each elements of the sensor device such as glucose, cellulose (paper), and PBA-SAM/AuNP and the changes in the gate surface potential.

3. Conclusions

In the present study, it was succeeded to detect low concentration of glucose using paper-based transistor. Paper plays important roles not only water-absorbing device as a micro fluidics but also gate electrode of FET transistor with the combination glucose recognition molecules/AuNP with cellulose. In conclusion, the paper-based transistor has the possibility of direct sampling medical device for the application of medical diagnosis.

References

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