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Effect of chemical surface modification on cell/graphene gate transistor

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Abstract

In this study, we investigated the effect of chemical surface modification on pH response for biological sensing with a graphene-based field effect transistor (GFET). We fabricated GFETs by use of chemical vapor deposition (CVD) method. In order to improve pH responsibility of GFETs, triphenylene derivatives (TP), which is utilized as a dispersant of carbon nanotubes, was modified based on hydrophobic interaction on the graphene surface. TP has carboxyl groups in a solution, so that pH responsibility can be induced on the GFET based on equilibrium reaction depending on pH. As a result of that, we could confirm the pH response with the TP-modified GFET in a real-time manner. Thus, we have found a possibility of real-time measurement of cell functions using the TP-based GFET. Eventually, we will be able to perform the simultaneous monitoring of electrical signal and cell morphology with an inverted microscopy by developing a GFET with a transparent substrate.

1. Introduction

Recently, the utilization of artificial cells or organs based on stem cells such as iPS has attracted attention in the field of regenerative medicine. Considering this background, the desired cells or organs must be of confirmed quality, safety and efficacy before transplantation. Therefore, the development of evaluation methods and tools, which enable to analyze them in a label-free and non-invasive manner, are expected. Currently, various researches and developments on bio-sensing technology have proceeded. Even among them, we think it is very important to detect ionic charges, because most biological phenomena are so closely related to ionic behaviors. Therefore, we focus on the biologically-coupled field effect transistor (bio-FET), which can quantitatively measure ionic behaviors as charge changes in a non-label and non-invasive manner, in this study. Actually, a silicon-based bio-FET is utilized for biological sensing, but the device is not adequate to observe clearly cell morphology by use of inverted microscopy, because the device is impenetrable to light. Therefore, a transparent bio-FET device will enable to not only monitor quantitatively electrical signals but also observe clearly cell morphology with an inverted microscopy, resulting in the simultaneous analysis of complex cellular functions from subjective and objective multiple elements. In this study, we focus on the graphene gate FET with transparency for cell sensing (Fig. 1). In particular, we try to enhance the ability of GFET by modifying functional molecules for pH response on the gate.

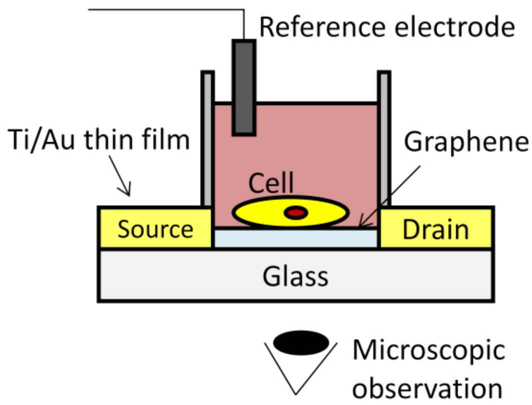

Fig. 1 Concept of cell/graphene gate transistor

2. Experimental section

2.1 Preparation of graphene FET (GFET)

Graphene was fabricated by Chemical Vapor Deposition (CVD) and transferred on a substrate. As substrates, we used two types of substrates; Si substrate with 280 nm thick SiO_2 layer and glass substrate. Then, Au/Ti thin film was coated as source and drain electrodes by sputtering method. The electrical properties (gate voltage (V_G) -drain current (I_D) transfer characteristics) of GFET in solutions were measured by the semiconductor parameter analyzer.

2.2 Chemical surface modification of GFET

Triphenylene derivatives (TP) [1] shown in Figure 2, was modified on the graphene surface in order to improve the pH response. The pH response of TP-modified GFET was investigated by the semiconductor parameter analyzer and the real-time monitoring system.

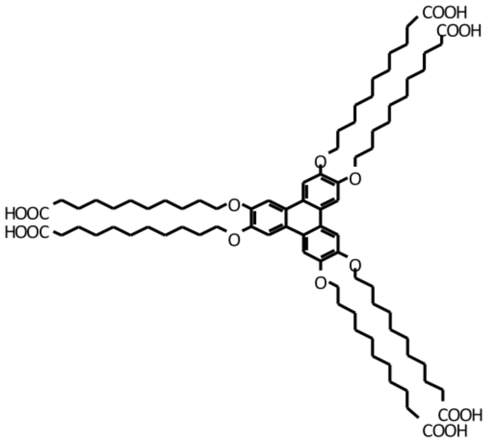

Fig. 2 Triphenylene derivatives (TP)

3. Result and discussion

Figure 3 shows the V_G-I_D electrical characteristics in the phosphate buffer solution (pH 7.4) using the non-modified GFET. We could observe the typical signal of GFET even in the solution, which was the bipolar V_G-I_D transfer characteristic. The transfer characteristic was also found to vary according to ion concentrations in solutions. Furthermore, Figure 4 shows the V_G shift for pH variation using the TP-modified GFET (a) and the non-modified GFET (b). The detected signals showed the improvement of pH response by the introduction of TP. This is because carboxyl groups in TP tethered on the graphene surface were dissociated by pH change resulting in the charge changes based on equilibrium reaction. Using the TP-based GFET, cell functions such as metabolism may be monitored, because cellular respiration contributes to pH change. Moreover, we plan to develop the TP-based GFET on a transparent substrate in order to monitor simultaneously cell morphology and electrical signal, because we need to analyze some information of living cells with various functions at the same time.

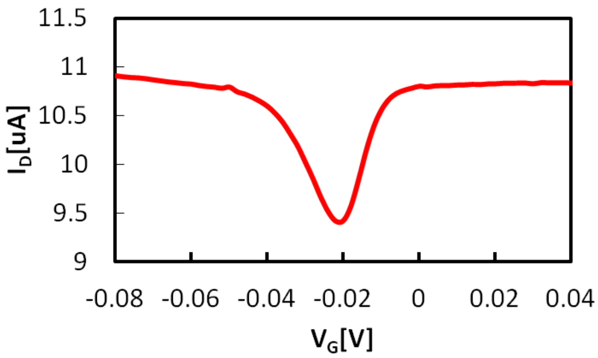

Fig. 3 The V_G-I_D electrical characteristics in the phosphate buffer solution (pH 7.4) using the non-modified GFET

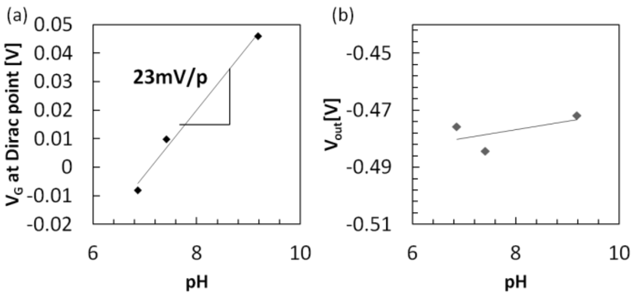

Fig. 4 Gate voltage (V_G) change for pH variation.
(a) TP-modified GFET and (b) the non-modified GFET.

References

[1] T. Yamamoto, *et al*. Improved Bath Sonication Method for Dispersion of Individual Single-Walled Carbon Nanotubes Using New Triphenylene-Based Surfactant, *Jpn. J. Appl. Phys.*, Vol. 47, No. 4 (2008)