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Electrolyte-Gated Graphene Field-Effect Transistors

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1. Introduction

Graphene, single-layer of graphite, have been intensively investigated in most recent due to its extraordinary high mobility without doping and behaviors as mass-less Dirac fermions [1-4]. Because electrical characteristics of graphene field-effect transistors (GFETs) is very sensitive for their surface conditions, gas sensor using GFETs have been reported [5]. This indicates that GFETs enable to apply to the chemical and biological sensors, electrical characteristics of GFETs in liquid solution have not been studied yet. In this work, we report electrical characteristics of electrolyte-gated GFETs.

2. Experimental

The graphene monolayer crystals were obtained from natural graphite by mechanical exfoliation. Figure 1 shows an optical micrograph of single-layer, bilayer and multi-layer graphene on the 300-nm-thick SiO_2/Si substrate. Raman spectroscopy was used to confirm the number of graphene layers as shown in Fig. 2. Apparent single peak of 2D band indicates the single-layer graphene [6]. In this work, we use only single-layer graphene as FETs' channel.

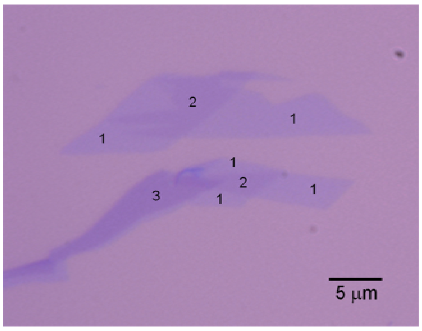

Fig. 1 Optical micrograph of single- and multi-layer graphene on 300-nm-thick SiO_2/Si substrate.

After confirmation of single-layer graphene with several micron cm^2, Ti (1 nm)/Au (30 nm) source and drain electrodes were formed by electron beam lithography, vacuum evaporation and lift-off process. The GFETs were immersed in a 10 mM phosphate buffer solution (PBS, pH 7), and their electrical characteristics were measured by semiconductor parameter analyzer (B1500A; Agilent Inc.).

3. Results and discussion

Figure 3 shows (a) drain current (I_D) versus back-gate voltage (V_{BG}) characteristics obtained in vacuum (1×10^{-3} Pa) at 295 K, and (b) the I_D versus top-gate voltage (V_{TG}) characteristics obtained in 10 mM PBS. An Ag/AgCl reference electrode (BAS Inc.) was used as the top-gate electrode. The transconductance (g_m) of the back- and top-gated GFETs were estimated to be 1 μS and 30 μS, respectively. The g_m of the top-gated GFETs showed 30 times larger value, indicating the formation of the thin electrical double layer on the graphene channel which acts as the top-gate insulator.

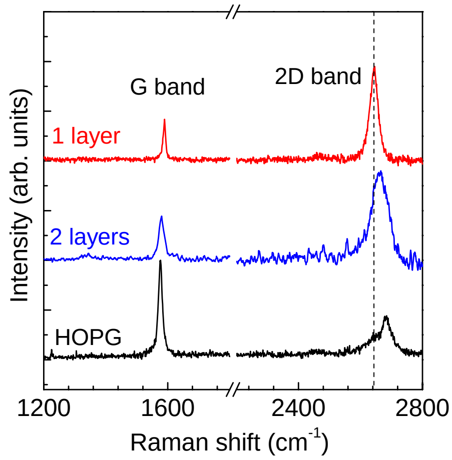

Fig. 2 Raman spectra of G- and 2D-bands for 1 and 2 layer graphene and highly oriented pyrolytic graphite (HOPG) excited by He-Ne laser of 632.8 nm.

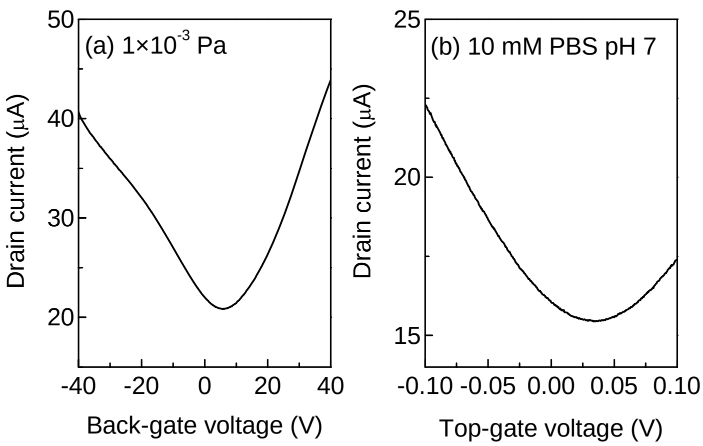

Fig. 3 Drain current versus gate voltage curves. (a) I_D-V_{BG} characteristics at 1×10^{-3} Pa and (b) I_D-V_{TG} characteristics in 10 mM PBS (pH 7).

Then, the pH dependence of the transfer characteristics and conductance of a GFET were evaluated. Figure 4 shows the I_D plotted as a function of V_{TG} of a GFET in various electrolytes with different pH value from 4.0 to 7.8. The Dirac points of the GFET shifted to positive direction with increasing pH value. These phenomena indicate that GFETs can detect the pH value by the electrical measurement. Plot of the time-dependent I_D for the GFET at V_{TG} of -80 mV in pHs from 4.0 to 8.2 was shown in Fig. 5. The different pH solutions were made from mixing of 10-mM phthalate (pH 4), phosphate (pH 7) and borate (pH 9) buffer solution. The I_D increased stepwise in pH from 4.0 to 8.2, and the I_D for each pH value is almost constant. These pH-dependent transport characteristics clearly show that GFETs can detect the electrolyte pH values.

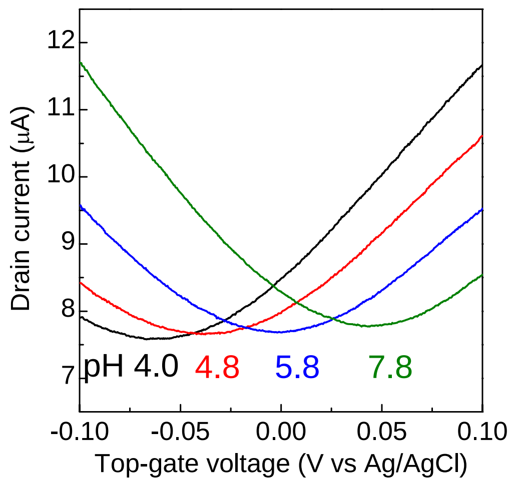

Fig. 4 Drain current as a function of top-gate voltage of a GFET in pH 4.0, 4.8, 5.8 and 7.8.

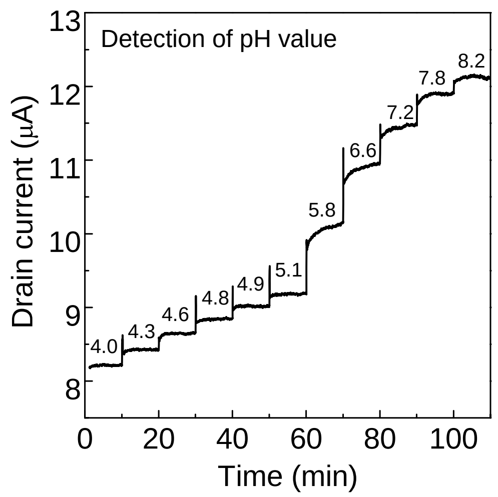

Fig. 5 Drain current versus time data of a GFET for pHs from 4.0 to 8.2.

4. Conclusions

We investigated electrolyte-gated GFETs for chemical and biological detectors. The GFETs showed good gate transfer characteristics in electrolytes; their transconductances were 30 times larger than those obtained under vacuum. Clear pH-dependent conductance was observed, indicating the potential for use of GFETs in pH sensors. Therefore, GFETs are a promising candidate for the real time chemical and biological sensors.

References

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