All Two-Dimensional Transparent and Flexible Transistor based on WS_2 and Few-Layer Graphene

Adha Sukma Aji[1], Toshiaki Shiiba[1], Kenjiro Fukuda[2,3], Hiroki Ago[1,3,4,*]

[1]Interdisciplinary Graduate School of Engineering Sciences, Kyushu University, Fukuoka, Japan
[2]Thin-Film Device Laboratory, RIKEN, Saitama, Japan
[3]PRESTO-JST, Saitama, Japan
[4]Institute for Materials Chemistry and Engineering, Kyushu University, Fukuoka, Japan
**ago@cm.kyushu-u.ac.jp*

Abstract

Two-dimensional materials, such as graphene and transition metal dichalcogenides (TMDCs), have been attracting a great deal of interest in recent years [1]. Beside of high transparency and flexibility, high carrier mobility of graphene and direct band gap of single-layer WS_2 make them a good combination for future flexible and transparent opto-electronic device [2,3]. In this work, we discuss the utilization of few-layer graphene (FLG) and WS_2 to realize all 2D material photodetector. The interesting part of this study is we found that the photodetector is worked by only applying FLG as electrode without any metal electrode on the device. Flexible and transparent parylene with 1 μm thickness was used as substrate and polymer dielectric insulator as well [4]. Moreover, parylene is extremely flexible so it wraps human skin easily as shown in Figure 1a. Additionally, Figure 1b shows an example of a transparent device on glass substrate.

FLG was chosen as electrode and backgate because of its lower sheet resistance compared to single-layer graphene. FLG and WS_2 were grown by using chemical vapor deposition (CVD) method. By using Cu-Ni foil, 10-12 nm thick of FLG was synthesized with CH_4 as carbon feedstock at 1050-1070 ºC. Moreover, large area single-layer WS_2 was grown on c-plane sapphire at 950 ºC by evaporating WO_3 powder and elemental sulfur precursor at 1070-1080 ºC and 165-170 ºC, respectively. FLG electrodes were patterned and etched by employing standard photolithography and O_2 etching process. After that, large-area WS_2, FLG electrode, and FLG backgate were transferred onto parylene with polystyrene support. Finally, polystyrene was stripped away by toluene bath several times.

The schematic view of our device is shown in Figure 1c. The sheet resistance of FLG is was 100 Ω/☐ measured by van der Pauw method. Figures 2a and 2b represent the device performance in dark environment. The I_d-V_g measurement shows field-effect mobility as high as 2 cm^2/Vs with 10^4 on/off ratio. Moreover, as shown in Figure 2b, the I_d-V_d characteristic implies ohmic-like contact as a result of clean interface between FLG electrode and WS_2 channel. Figures 3a and 3b show the device performance under visible light (532 nm). The negatively shifted charge neutrality point under illumination suggests that the generated current is mostly accumulated from photogating effect [5]. Figure 3b plots photoresponsitivity as a function of FLG backgate applied voltage. The photoresponsitivity reached 70 μA/W at V_g = 30 V. $I_{illuminated}/I_{dark}$ ratio of the device was around 15 when illuminated with 6.5 mW/cm^2 light. From the photoresponsitivity result, external and internal quantum efficiency (EQE and IQE) value are extracted. We found that the EQE value is only around 0.12% under illumination. Such small EQE value is expected since single-layer WS_2 is transparent and pass through most of the light. On the other hand, IQE value reached 9% from single-layer WS_2. IQE value represent the number of charge per absorbed photons. Hence, single-layer WS_2 can generate a large number of charges even though it has high transparency.

The usage of metal-free FLG electrode, good photodetection ability of single-layer WS_2, and flexible parylene is expected to open new insight into novel 2D materials-based wearable opto-electronic devices.

References

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Figures

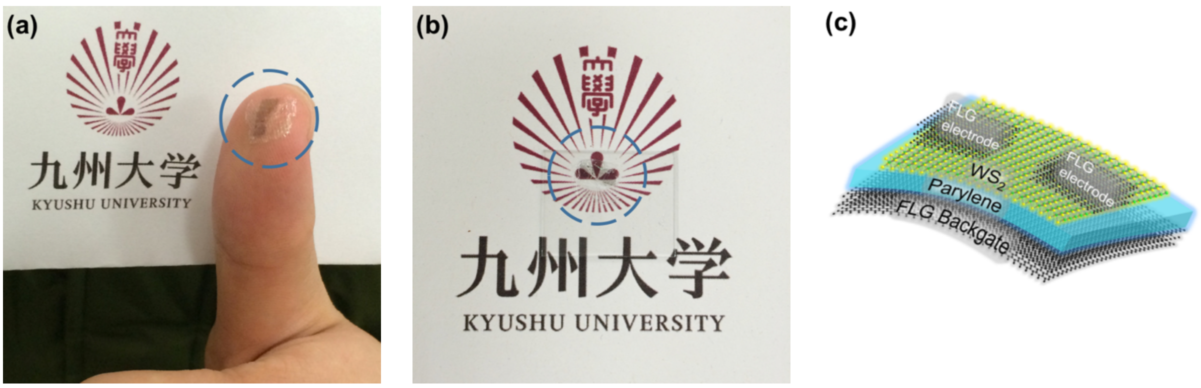

Figure 1. (a) Photograph of the 2D material device on human skin. (b) Photograph the transparent device with parylene substrate supported by glass. (c) Schematic view of the device.

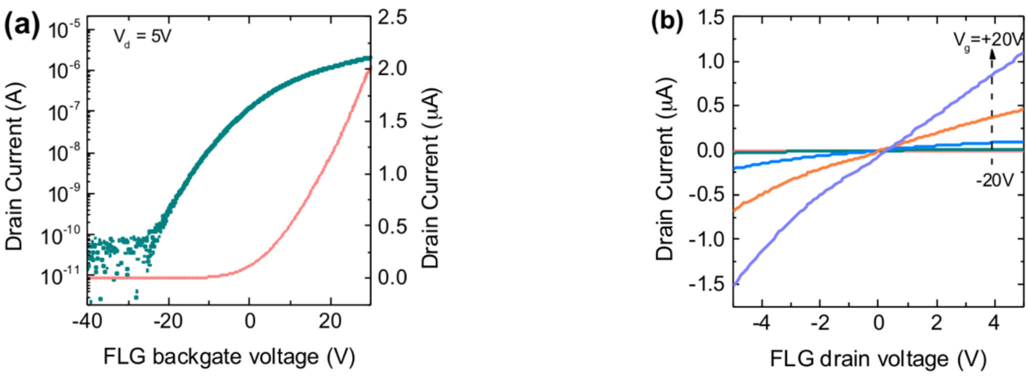

Figure 2. (a) I_d-V_g and (b) I_d-V_d characteristics of the device in dark.

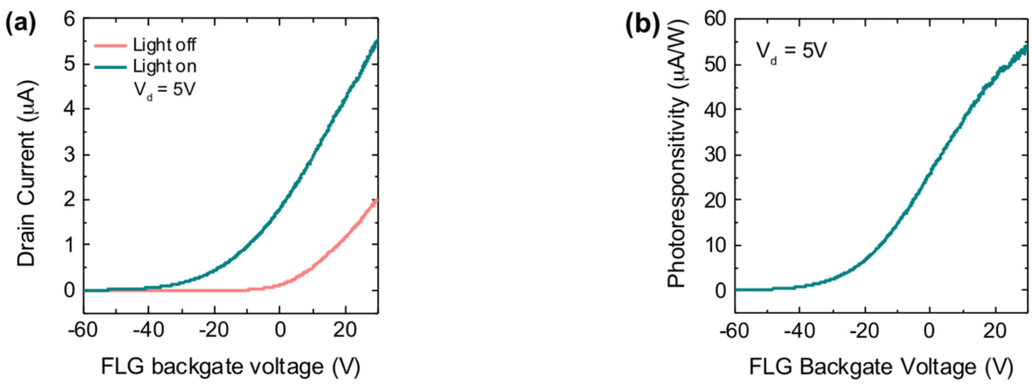

Figure 3. (a) I_d-V_g curve and (b) photoresponsitivity of the device under light illumination.