B-5-02
Extended Abstracts of the 2019 International Conference on Solid State Devices and Materials, Nagoya, 2019, pp87-88

Photoresponsivity Evaluation of a Multi-Channel Graphene Nanoribbon based Field Effect Transistor Structure

Jowesh Avisheik Goundar[1], Ken Suzuki[2] and Hideo Miura[2]

[1] Deaprtment of Finemechanics, Graduate School of Engineering, Tohoku University
6-6-11, Aobayama, Aoba-ku, Sendai
Miyagi 980-8579, Japan
Phone: +81-22-795-4830 E-mail: jowesh@rift.mech.tohoku.ac.jp
[2] Fracture and Reliability Research Institute, Graduate School of Engineering, Tohoku University
6-6-11-716, Aramaki, Aoba-ku, Sendai
Miyagi 980-8579, Japan
Phone: +81-22-795-4830

Abstract

In order to address the issue of large fluctuations in GNR based devices, a novel multi-channel GNR based structure is proposed. Furthermore, the electronic behavior was studied by fabricating a GNR based field effect transistor (FET) and tested with a light source to investigate photoresponsivity of the device. Photoresponsivity is a property of semiconductors, and the experimental validation of high photoresponsivity in the GNR-FET, indicates large potential of GNR in semiconductor devices.

1. Introduction

As electronic components are being miniaturized, the electronic industry is slowly approaching the limits of what is achievable using the conventional approach with silicon as a semiconductor material. Graphene, a one atom thin layer of carbon material, is considered a potential replacement due to its unique electronic properties [1]. Graphene sheet has no energy gap (band gap) which limits its potential in direct application in electronic devices. Many efforts has been emphasized to modify and enhance the electronic properties, which makes graphene applicable for use in applications such as photodetection, strain-sensing and memory storage devices. However, these efforts has not proven a band gap opening in graphene structures. On the other hand, graphene nanoribbon (GNR) has proven to show band gap opening that is tunable by varying the ribbon width, below 70 nanometer [2]. The narrower the ribbon width, the larger the band gap. This is the first material that has shown this very unique phenomena, that is, having band gap that is totally dependent on physical parameter of the material. The major challenge is the fabrication of GNR structures less than 70-nm using industry standard processes that is easily adaptable. Many researchers have investigated the properties of GNR, however, large fluctuation in electronic properties was observed due to the use of single nanoribbon per measurement device [3]. This limits the reliability of GNR based devices.

In this study, a novel structure has been proposed using a multi-channel GNR with finger-like metallic electrodes to enhance the reliability by effectively countering electronic noise to reduce fluctuations illustrated in Fig. 1. Here, we report on the successful fabrication process of 40-nm multi-channel

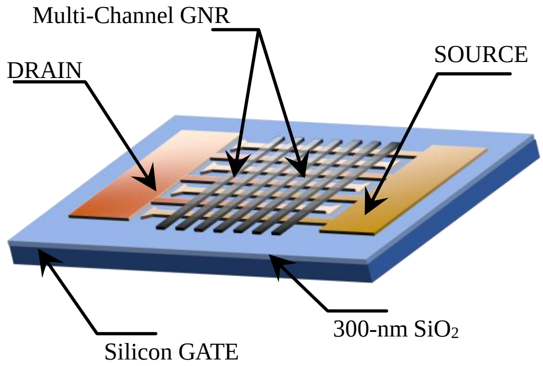

Fig. 1 Schematic of the proposed multi-channel GNR-FET structure for enhanced electronic performance.

GNR with finger-like metallic electrodes. The photoresponsivity was tested by fabricating a multi-channel GNR based field effect transistor (GNR-FET) structure with finger-like metallic electrodes.

2. Development of GNR-FET

Graphene was synthesized on Cu foil inside an ultra-vacuum chemical vapor deposition chamber with acetylene as the carbon precursor gas. The synthesized graphene was then transferred to a heavily doped n-type silicon substrate with 300-nm silicon dioxide (SiO_2) using polymethyl-metha acrylate (PMMA) polymer as an assistive transfer medium, later etched in acetone solution. The source and drain electrodes, both composed of bi-layer metal, platinum and gold, were then deposited on the patterned substrate using electron beam deposition method. Furthermore, the graphene sheet was patterned to 40-nm ribbon widths, 60 nanoribbons between the source and drain electrodes as a multi-channel GNR, using conventional electron beam lithography technique followed by plasma enhanced etching with oxygen gas.

The validation of the process was done using scanning electron microscopy (SEM) and Raman spectroscopy as shown in Fig. 2 and 3, respectively. Fig. 2(a) and (b) shows the fabricated GNR-FET with multi-channel GNRs and the source and drain metallic electrodes. The minimum ribbon width achieved by this process was 40-nm as shown in

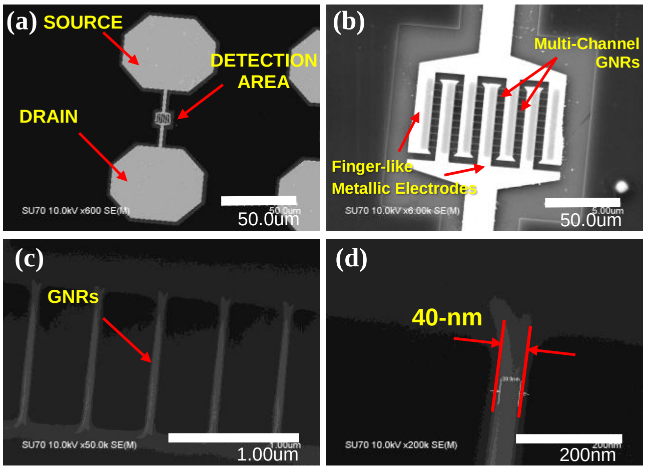

Fig. 2 SEM images of the a) structure of the GNR-FET, b) detection area with metallic electrodes and multi-channel GNRs, c) high magnification image of the GNRs, and d) confirmation of ribbon width approximately 40-nm in width.

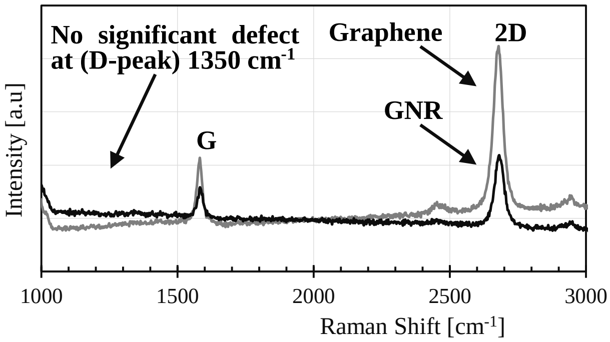

Fig. 3 Raman spectrum to quantitatively validate the peaks of graphene and GNR.

fig. 2(c) and (d). The Raman data in Fig. 3 confirmed the presence of graphene and the ratio of intensity of 2D to the G peak was greater than 2, which indicated the presence of single layer graphene. Also, it was observed that the intensity of the G and 2D peak decreased in the GNR structure, as expected. In addition, absence of D peak at 1350 cm^{-1} indicated that there was no significant defects. Thus, this confirmed that the process developed is reliable and high quality.

3. Electronic performance of the fabricated GNR-FET

The photoresponsivity was calculated from the I-V characteristics of the fabricated GNR-FET. The effect of the gate voltage on the fabricated transistor is shown by the $I_d - V_g$ curve for two drain voltages, $V_D = 0$ and 100 mV, in Fig. 4(a). In addition, the effect of light-induced current was also observed when the transistor was tested with a light on situation. The gating effect to control the flow of current through the GNR channel was clearly observed in this device, including the light induced current (red line). The graph indicated effect similar in a p-doped type semiconductor material.

Furthermore, the photocurrent was determined from the I-V curve of drain current, I_d, versus the drain voltage, V_d, in fig. 4(b). Photocurrent is the difference of light on and off curve. The average photocurrent of this device obtained per unit area was 261.44 A/m^2. Photoresponsivity, on the other hand, is a function of photocurrent divided by input light intensity in watts. The device was tested using a white light source of intensity 1 mW, hence, the photoresponsivity of this device corresponded to be 2.6×10^5 A/W.m^2. In contrast, a previously fabricated graphene based FET (G-FET) showed a photoresponsivity value of 3×10^3 A/W.m^2 [4]. A clear enhancement of about 100 times was observed in a GNR-FET.

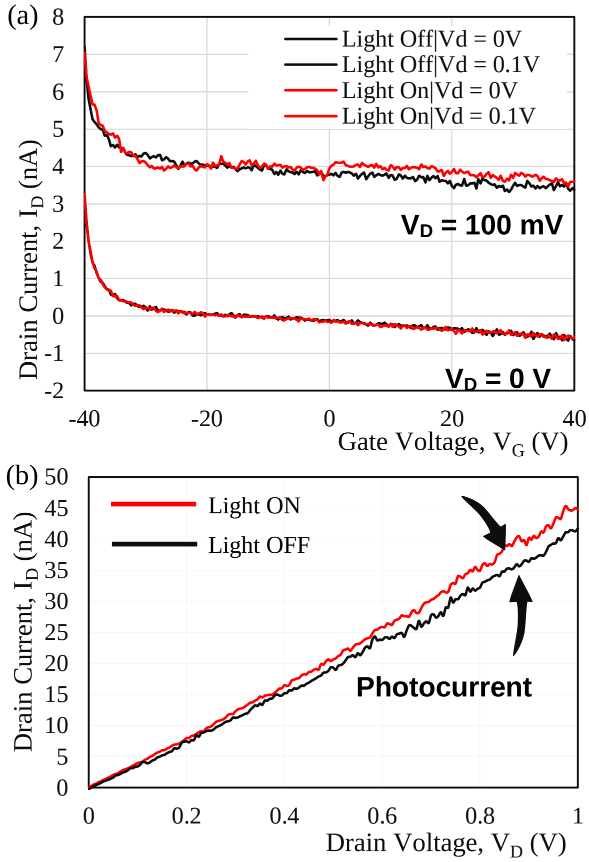

Fig. 4 a) The I-V characteristics for a curve for the I_D versus V_G for $V_D = 0$ and 100 mV, and b) I_D versus V_d curve to determine the photocurrent of the GNR-FET.

3. Conclusions

This study confirms the effectiveness of the new proposed structure to reduce electronic fluctuations. In addition, the photonic behavior in GNR was validated to be higher than that of graphene based structure, clearly indicating the large potential of GNR in semiconductor devices.

Reference

[1] A. Castro *et al., Reviews of Modern Phys.* (2009) 81.
[2] S. Sasaki *et al., Proc. of ASME 2016 International Mechanical Engineering Congress and Exposition* (2016).
[3] M. Liang *et al., ChemPhysChem Minireviews* (2012) 14
[4] J. Goundar *et al.,* Proc. of ASME 2018 *International Mechanical Engineering Congress and Exposition* (2018).