A Study of Structure Dependent Electrical Properties of Suspended Graphene Nanoribbon in a Transmission Electron Microscope

Japan Advanced Institute of Science and Technology[1], Shibaura Institute of Technology[2], Hitachi Cambridge Laboratory[3]

°Chunmeng Liu[1], Xiaobin Zhang[2], Jiaqi Zhang[1], Muruganathan Manoharan[1], Hiroshi Mizuta[1,3] and Yoshifumi Oshima[1,*]

***E-mail: oshima@jaist.ac.jp**

The electrical properties of graphene nanoribbon (GNR) depends on the width, length and edge structure. Recently, it has been investigated in both first principle calculation and experiments [1-3]. However, in experiment, most of GNR devices have been fabricated with substrate underneath, which can change the electrical properties due to dielectric screening of the substrate. The electrical properties of substrate-free GNR have been attempted to be measured [4], but its edge structure dependence has not been clarified yet due to difficulty in the fabrication of the suspended GNR.

In this study, we established to fabricate a suspended GNR device, which can realize the controllable structure of GNR by electron beam in aberration-corrected TEM (AC-TEM). We measured the electronic properties of the suspended GNR simultaneously with observing its structure. As shown in Fig.1a, the suspended GNR device was fabricated on a custom Si/SiN chip with electron-transparent windows. The electrodes and pads with 5 nm chromium and 40 nm gold in thick were deposited on the chip, then nano-gaps were made at the center of electrodes by using focused ion beam (FIB). Finally, chemical vapor growing monolayer graphene was transferred onto the prepared chip and patterned using electron beam lithography (EBL).

The suspended GNR fabricated across the nano-gap is shown in the TEM image of Fig.1b, which has a width about 250nm. The corresponding FFT pattern in Fig. 1c show that the GNR is composed of monolayer graphene. Then, this suspended GNR was cleaned by Joule heating, and sculpted by a convergent electron beam in TEM mode, until its width was reduced down to several nanometers. During the thinning process, the resistance of the GNR increased with reducing its width. Finally, we successfully fabricated an ultranarrow GNR with width of 1.8 nm, as shown in Fig.2a. By comparing I-V curve between initial 250nm wide GNR and final 1.8nm GNR (Fig.1d and Fig.2b), we find that the electrical transport property of GNR change from metallic to semiconducting. The transport gap of 300 meV was estimated for final 1.8nm GNR.

References:

[1] M.Y. Han, B. Özyilmaz, Y. Zhang, and P. Kim, Phys. Rev. Lett. 98, 206805 (2007).

[2] L. Yang, C.-H. Park, Y.-W. Son, M.L. Cohen, and S.G. Louie, Phys. Rev. Lett. 99, 186801 (2007).

[3] G.Z. Magda, X. Jin, I. Hagymási, P. Vancsó, Z. Osváth, P. Nemes-Incze, C. Hwang, L.P. Biró, and L. Tapasztó, Nature 514, 608 (2014).

[4] M.E. Schmidt, M. Muruganathan, T. Kanzaki, T. Iwasaki, A. M. M. Hammam, S. Suzuki, S. Ogawa, H. Mizuta, Small 2019, 1903025

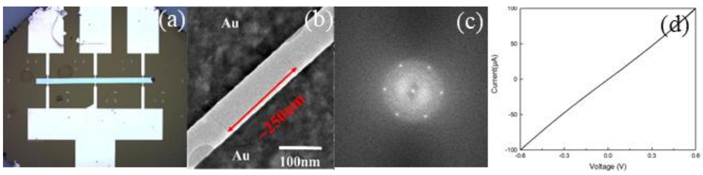

Fig 1. (a) The fabricated GNR device, (b) TEM image of suspended GNR, its width is indicated by red arrow, (c) The corresponding FFT pattern in (b), (d) I-V curve of wide GNR in (b).

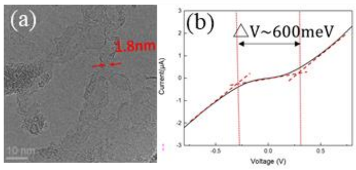

Fig 2. (a) TEM image of the fabricated narrow GNR with a width of 1.8 nm. (b) I-V curve of narrow GNR in (a).