Frequency dependence of bridging graphene nanoribbons by dielectrophoresis technique

Wahyu Waskito Aji[1], Yuki Usami[1,2], Hadiyawarman[1,2], Hirofumi Tanaka[1,2,*]

[1]Department of Human Intelligence Systems, Graduate School of Life Science and Systems Engineering, Kyushu Institute of Technology, Kitakyushu, 808-0196, Japan
[2] Research Center for Neuromorphic AI Hardware, Kyushu Institute of Technology, Kitakyushu, 808-0196, Japan.
E-mail: tanaka@brain.kyutech.ac.jp

[Introduction] Graphene is one of the most attractive organic materials due to high carrier mobility and conductivity. Various reports suggested producing graphene with sub-10 nm width, called graphene nanoribbons (GNRs), to make the finite band gap[1)]. In our previous work, sub-10 nm GNRs can be obtained by opening single-walled carbon nanotubes (SWNTs) along a line or longitudinal unzipping[2)]. Although this synthesis process can produce sub-10 nm width GNR and is suitable for mass production, the application of unzipped GNR is still limited because of the difficulty to separate the GNRs from excess SWNTs, and to assemble the GNRs to make electronic devices. In this work, we tried to assemble and align the unzipped GNRs and separate it from the excess SWNTs using frequency dependent dielectrophoresis (DEP) method.

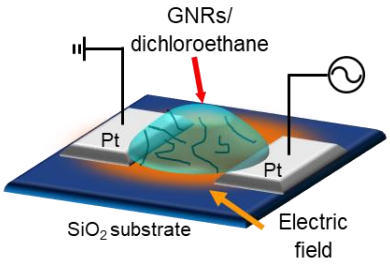

Figure 1. DEP setup.

[Experiment] The GNRs was synthesized by unzipping 0.01 mg of SWNTs using 3mg poly [(*m*-phenylenevinylene) -*co*-(2,5-dioctoxy-*p*-phenylene-vinylene)] (PmPV) in 10 ml dichloroethane solvent. The solution was bath sonicated for 50 minutes to initiate unzipping process. The GNRs solution was casted to Ti/Pt electrodes and followed by DEP process. The DEP was conducted by applying AC bias voltage for duration of 2 min and by varying the frequency; ranged from 500 kHz to 15 MHz as shown in figure 1. GNRs and electrode was cleaned and annealed in ambient environment at 200°C for 1.5 hours after DEP process to remove PmPV and increase the adhesion between GNRs and electrode. Fabricated samples were measured by atomic force microscopy and Raman spectroscopy (533 nm laser) for structural evaluation.

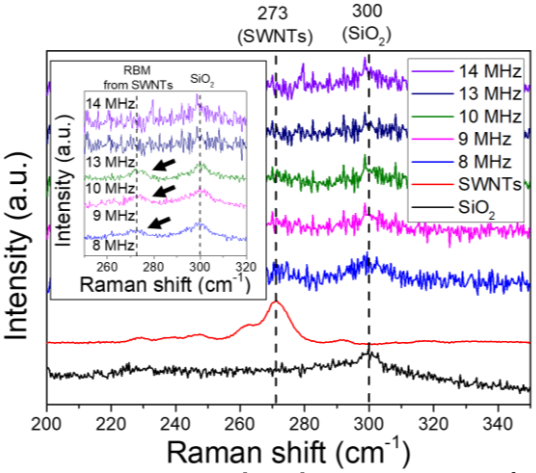

Figure 2. Frequency dependent RBM spectrum of trapped GNRs by DEP. The 273 cm^{-1} SWNTs RBM peak was disappeared 13 MHz or more in inset.

[Results and discussion] The presence of D, and G band peak in Raman spectrum confirms that the unzipped GNRs with SWNTs were successfully assembled and aligned by DEP method. Radial breathing mode (RBM) of Raman spectrum (~273cm^{-1}) showed that SWNTs residue remains trapped in GNRs by DEP. The Raman RBM result at figure 2 shows that RBM peak was missing at frequencies higher than 13 MHz, which indicated that only GNRs can be trapped. This RBM peak correlates with metallic SWNTs peak from Kataura plot. This indicates that only metallic SWNTs and semiconductive GNRs remained after unzipping process. *I-V* curve in figure 3 showed current is decreased at high frequency region, which also indicates that only semiconductive GNRs are trapped between electrodes. As a result, The separation of GNRs from SWNTs was successfully performed by DEP method, which is promising for organic device application.

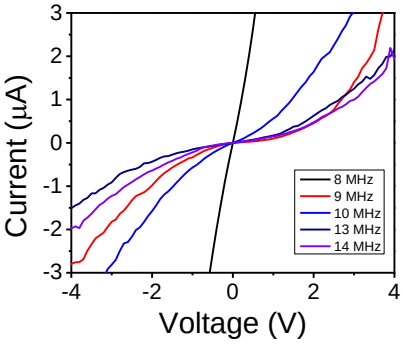

Figure 3. Frequency dependent I-V curve of trapped GNRs.

Reference:

1) Melinda Y. H. et al., Phys. Rev. Lett. **98**, 206805 (2007).
2) M. Fukumori et al., Jpn. J. Appl. Phys. **56**, 06GG12 (2017).