Electric properties of Organic Field Effect Transistor by Directly Grown Poly(3-hexylthiophenel) Crystalline Nanostructures on Graphene Electrode

Jinwoo Choi*, Hyosub An² and Jongwan Jung¹**

¹ Graphene Research Institute, Sejong Univ.
² Institute of Nano and Advanced Materials, Sejong Univ.
98, Gunja-dong, Gwangjin-ku, Seoul 143-747, South Korea
Phone: +82-3408-3688 E-mail: *nanodevice403@gmail.com/ **jwjung@sejong.ac.kr

1. Introduction
Organic semiconductor has attracted a lot of attention since it has advantages such as lightweight, flexibility, high-conductivity, and cost-effectiveness. The device performance of organic field effect transistors (OFET) is currently limited by the contact resistance between metal electrodes and organic semiconductors. Contact resistance depends on the morphology of the interface. For example, the typical field effect mobility value for the most common conjugated polymer, poly(3-hexylthiophene) (P3HT), varies by several orders of magnitude depending upon the processing parameters. Appropriate source and drain (S/D) electrode materials with excellent contact and highly ordered crystalline organic semiconducting materials are the key. Carbon materials such as CNT, graphene are promising candidate for electrode materials in OFETs because of their work function (4.7-5.2 eV) closely aligned with the HOMO level of many conjugated polymers including P3HT. Besides, \(\pi-\pi\) interaction between carbon materials and the conjugated polymers is expected to result in better charge injection. Recently, B. K. Sarker et al [1] demonstrated a bottom-up approach to fabricate OFETs by growing P3HT crystalline nanowires on solution processed aligned array SWNT interdigitated electrodes which exploit strong \(\pi-\pi\) interaction. In this report, we will demonstrate OFETs with directly grown P3HT crystalline nanowires on interdigitated CVD-grown graphene electrode.

2. Fabrication and Measurement

Fig. 1 is schematic of the overall process. The monolayer graphenes were synthesized on copper (Cu) foil by Chemical Vapor Deposition (CVD) method using a mixture of methane (CH\(_4\)), argon (Ar) and hydrogen (H\(_2\)) for 15 min at 950 °C. Then, the synthesized graphene was transferred to 300 nm SiO\(_2\) /Si substrate. Graphene source/drain electrode was patterned by photolithography and etched by O\(_2\) plasma. After patterning metal pad, Au metal was deposited on the graphene source/drain electrode by thermal evaporator and lifted off. OFETs measured in this experiment had interdigitated structure with channel length (L) of 2 \(\mu m\) and total channel width (W) of 80 \(\mu m\). The fabricated graphene and Au electrode are shown in the Fig. 2 (a) and (b). The nanostructures have been fabricated from Regioregular P3HT using a solution method. P3HT powder was dissolved in anisole with a concentration of 1 mg/ml at 90°C in a glass vial. A chip of graphene electrode was then immersed inside the P3HT solution. Then it was cooled down to room temperature at a rate of ~ 40 °C/h and kept for 12 hrs for P3HT crystallization.

![Fig. 1 Overall process flow for this work.](image_url)

![Fig. 2 (a, b) Optical images of interdigitated electrode pattern (Au and Graphene). (c) After P3HT synthesis on Au. (d) Raman spectrum of the synthesized graphene.](image_url)

Fig. 2(c) shows the optical image after P3HT synthesis on Au pad. The properties of the synthesized graphene were characterized by Raman spectrometer. Fig. 2(d) shows Raman spectrum of a single layer graphene. high 2D/G peak ratio is a indication of single layer graphene. The morphology of the self-assembled nanostructures is observed by non-contact mode atomic force microscope (AFM). The OFET characteristics were measured using
B1500A semiconductor analyzer connected to a probe station inside a black box at room-temperature.

3. Results and Analysis

Fig. 3 and Fig. 4 show non-contact mode AFM images of P3HT nanostructure in channel region between S/D electrode. Fig. 5 compares the Id-Vd for OFETs with graphene electrode and metal electrodes. OFET with graphene electrode shows much higher drain current than that with metal electrode. The process parameters setup to improve gate modulation characteristics of P3HT-OFETs through controllable synthesis of P3HT nanowire on graphene electrodes are underway.

![Fig. 3 Non-contact mode AFM image of P3HT nanostructure in channel region between Au S/D electrode.](image1)

![Fig. 4 Non-contact mode AFM image of P3HT nanostructure (nanowire) in channel region between graphene S/D electrode.](image2)

![Fig. 5 Id-Vd of OFETs with graphene electrode and metal electrodes.](image3)

4. Conclusions

In this work, we demonstrated a bottom-up approach to fabricate OFETs by growing P3HT crystalline nanowires on interdigitated CVD-grown graphene electrodes which exploit strong π-π interaction. The measured P3HT-OFETs with graphene electrode show much higher drain current than those with Au electrode. The process parameter setup to improve gate modulation characteristics of P3HT-OFETs through controllable synthesis of P3HT nanowire on graphene electrodes are underway.

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