Characterization of Single-Walled Carbon Nanotube and Graphene-Based Field-Effect Transistors

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Abstract—We describe a transparent and flexible field-effect transistor (FET) made from graphene and single-walled carbon nanotubes (SWNT) hybrid system. Graphene and vertically aligned SWNTs simultaneously grown by alcohol catalytic chemical vapor deposition (ACCVD) were employed as channel and source-drain electrode, respectively. Gate electrode was also made of SWNTs separated with a thin poly(vinyl alcohol) (PVA) film. Characterization of this functioning FET is described.

I. Introduction

Single-walled carbon nanotubes (SWNT) and graphene are expected to be an important components of field-effect transistors (FETs) used in next generation flexible and transparent electronic devices. Several studies have been performed to realize transparency and flexibility using inorganics, organics, carbon nanotubes, and graphene in FET. By using SWNTs as source, drain and gate electrodes as well as channel, we have demonstrated a high performance transparent and flexible FET in our previous study [1]. The transparency is ensured by not using metal electrode, and the flexibility characteristics were superior due to the strength of SWNTs and SWNTs network. Here we describe the fabrication of a hybrid device that incorporate graphene for channel and vertically aligned SWNTs [2] for the source, drain, and gate electrodes. Graphene and SWNTs were grown simultaneously in an alcohol catalytic CVD (ACCVD) [3] process with an optimized synthesis condition for each material. The resulting devices have thin morphologies and are highly transparent throughout the visible range. Furthermore, characterization of the electrical responses reveals the key properties and provides some preliminary insights into the physics and material aspects of electrical contacts between SWNTs and graphene.

II. Experiments

The SWNT and graphene FETs were fabricated on poly(vinyl alcohol) (PVA) film with a thickness of ~20 μm. Each electrode was fabricated as follows. First, we used standard optical photolithography processes to generate patterns at desired locations on Ni foil. Al (15 nm) and Co (0.2 nm) catalysts were deposited by e-beam sputtering. The photoresist layer was then removed in acetone and following sonication in isopropyl alcohol. Using the patterned substrate, SWNTs and graphene were synthesized simultaneously at 850 ^{o}C in 3 min. CVD period using ACCVD method [3]. SWNTs and graphene film were then dry transferred from the metal foil onto PVA film.

The device substrate and dielectric layers were fabricated as follows. An aqueous polymer solution was prepared by dissolving PVA powder into distilled water. The solution was spin-coated over the SWNTs and graphene acting as the active layer and the global gate, and then dried at 100 ^{o}C for 1 hour on a hot plate. The devices were characterized by resonance Raman spectroscopy, optical absorbance spectroscopy, and SEM observation. Transfer characteristics were evaluated using a semiconductor parameter analyzer, and all measurements were performed at room temperature.

III. Results and discussion

We have identified the devices with SEM images and resonance Raman spectra of the fabricated device in which SWNTs acted as the source and drain electrodes, and graphene acted as the channel. The FET device was functional showing the source-drain current response as a function of gate voltage in back-gated SWNTs. The anomalous transfer characteristics probably due to the contact between graphene and vertically aligned SWNTs will be discussed.

Acknowledgment

Part of this work was financially supported by Grant-in-Aid for Scientific Research (22226006 , 19054003, 23760179 and 23760180), JSPS Core-to-Core Program, and Global COE Program 'Global Center for Excellence for Mechanical Systems Innovation'..

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