Bio-electronics Applications of Carbon Nanotube Thin Films

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1. Introduction

Flexible, body-worn healthcare/medical devices have the potential to revolutionize preventive medical care and health promotion. Carbon nanotube (CNT) thin films are promising bio-electronic materials for transistors, biosensors, and other passive components to build such wearable devices because of the excellent electronic and mechanical properties and biocompatibility.

In our recent works, we have studied CNT thin film technologies from the growth of CNTs and the thin film formation to device fabrication and characterization on flexible and stretchable films. High-mobility flexible thin-film transistors (TFTs) and their integrated circuits have been realized on a transparent plastic film. We have also demonstrated extreme stretching ability of CNT TFTs on dimethylpolysiloxane (PDMS) thin film. Highly-sensitive, flexible biosensors with excellent uniformity in the sensing property have also been realized.

2. Flexible/stretchable CNT TFTs and ICs

First, we have developed a method to realize high-mobility CNT thin films, based on a gas-phase filtration and transfer process. CNTs were grown by a floating-catalyst CVD technique. The CNT network was collected by filtering through membrane filters at room temperature. The CNT network was transferred from a membrane filter to the substrate with electrodes of TFTs. This technique enables to form CNT films with high mobility and controllable threshold voltage on a plastic film. A TFT fabricated on a Si substrate with the transfer technique exhibited a high mobility of 634 cm^2/Vs with on/off ratio of $6x10^6$.

CNT films can also be used as electrodes and interconnections, which are flexible, transparent, stable, and free of rare metals. By using CNT transparent conductive films, we realized all-carbon TFTs and ICs, in which the electrodes and interconnections consist of CNT film and the insulators consist of PMMA. The all-carbon device was able to be formed into three-dimensional dome-shape devices by the thermo-pressure forming technique. We also demonstrate extreme stretching ability of all-carbon devices fabricated on PDMS thin film.

3. CNT biosensors

One of critical issues of CNT biosensors is reproducibility in terms of device fabrication and characteristics. In this work, uniform and ultra-clean CNT thin film was formed on a plastic film by the dry transfer process based on the floating-catalyst CVD technique. Both amperometric (electrochemical) and potentiometric (field-effect transistor) sensors were fabricated using the CNT thin film. To prevent the contamination, the CNT thin film was covered with an oxide layer during the fabrication process.

The electrochemical property of the CNT-thin film electrode was investigated by measuring cyclic voltammetry with $K_3[Fe(CN)_6]$. The fabricated CNT-thin film electrodes exhibited almost ideal characteristics. The quartile potential was 60.4 mV, which was close to an ideal value of 56.4 mV. The steady-state current (I_{SS}) of the micro-electrodes well-agreed with the theoretical diffusion-controlled I_{SS}. The device-to-device variation in steady state current was less than 6%, showing excellent reproducibility of CNT amperometric sensors.

We also fabricated CNT TFT-based potentiometric sensors on a plastic film (Figure). The device-to-device variation in the drain current was as small as 7%. To detect dopamine, the CNTs were decorated with pyrene-1-boronic acid. The boronic acid chemically react with dopamine, so that, boron is negatively charged. An increase in hole current was observed when dopamine solution was applied. High-sensitivity and wide-range detection of dopamine was confirmed. The limit of sensitivity was 10 pM and the dynamic range was 10^6.

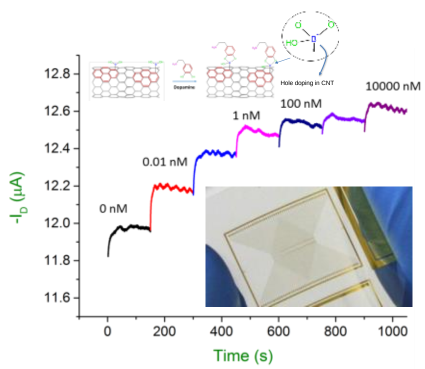

Figure. High-sensitivity detection of dopamine by biosensor based on pyrene-1-boronic-acid-decorated CNT TFT