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Fabrication of Supported Lipid Bilayer (SLB) and Nanotube Transistor Hybrid Biosensing Platform Using Microfluidic Channels

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***Abstract*—Here we demonstrate a simple way to pattern SLBs onto desired area of carbon nanotube (CNT) films using microfluidic channels. Integrated systems in which all-semiconducting nanotube network transistors are coated directly with lipid bilayers are demonstrated. This new system forms a mechanically robust, stable platform for various sensing applications. Finally, in contrast to all previous studies using nanotubes for membrane interrogation, we use a simple, robust fabrication process based on printable semiconducting nanotube ink, which is compatible with mass-manufacturing in roll-to-roll, flexible electronic applications. This will allow direct translation of the technology into a low cost, next generation measurement system for electrophysiology. This approach will find broad applications in electrophysiology.**

I. Introduction

Supported lipid bilayers (SLBs) have been a model sensing platform in biophysical studies of membrane biology and chemistry[1]. As an artificial cell membrane, a SLB has the ability to sustain integral membrane proteins and maintain them in a fully functional state. Due to this feature, it has been widely utilized in biosensing applications with ion channels [2-4]. Previously researchers demonstrated direct integration of lipid bilayers onto metal electrodes, using them to sense ion channel currents in large areas[5]. CNT FETs have been playing an important role as a versatile sensing platform for biological and electrochemical applications[6]. The advantages of CNTs, such as the size comparability to biomolecules and the ultra-high sensitivity to changes in local environments offer promising candidates for advanced sensing materials to achieve a significant improvement in sensing performance. Thus, the SLB and CNT FET hybrid devices can be conceivable to exploit these advantages, and thereby a simple, durable and ultra-sensitive biosensing platform can be feasible for the next generation bionanoelectronic sensor.

In this report, we demonstrate an integrated nano-bio system: The biological membrane and the all-semiconducting nanotube network are all part of one integrated device, with potential for mass manufacturing. Importantly, the fabrication process to easily deposit and pattern supported lipid bilayers onto CNT devices can be utilized in various applictions. In addition, this hybrid device can provide as a sensing platform allows new approach toward low noise nanobioelectronic system that is capable of investigating interactions between biomolecules and electronic devices. With these features, our system could provide a useful tool in the bionanosensnig applications.

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II. Experimental

A. Device Fabrication

The fabrication steps are schematically illustrated in Fig. 1(a-i). Prior to CNT deposition, the quartz wafers were treated with hot piranha solution for about an hour followed by DI water rinse to achieve a clean surface before the surface modification. The surface was treated with 1% APTES in isopropanol, then semiconducting ink

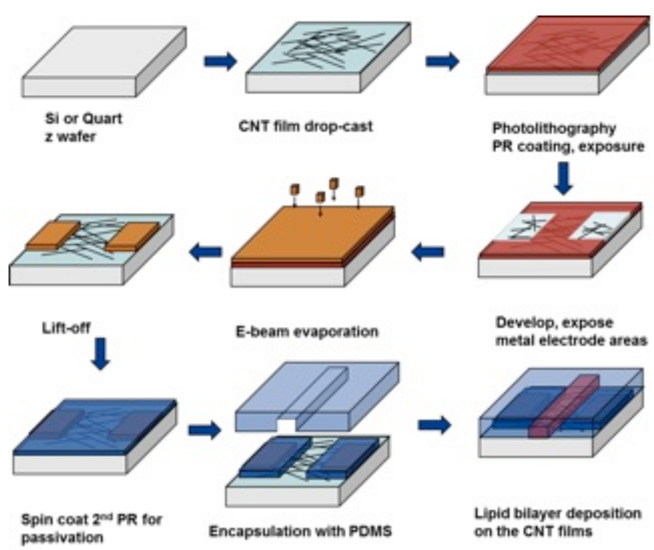

Figure 1 Fabrication processes. (a) Clean 4” Si or Quartz wafer (b) CNT film deposition after surface modification using APTES (c) PR coating on top of CNTs (d) Pattern and develop for metal evaporation (e)Ti/Pd/Au e-beam evaporation (f) electrode patterning by lift-off (g) 2nd PR coating for passivation (h) encapsulation PR passivated CNT transistor (i) lipid bilayer deposition by introducing lipid vesicle solution into microfluidic channel.

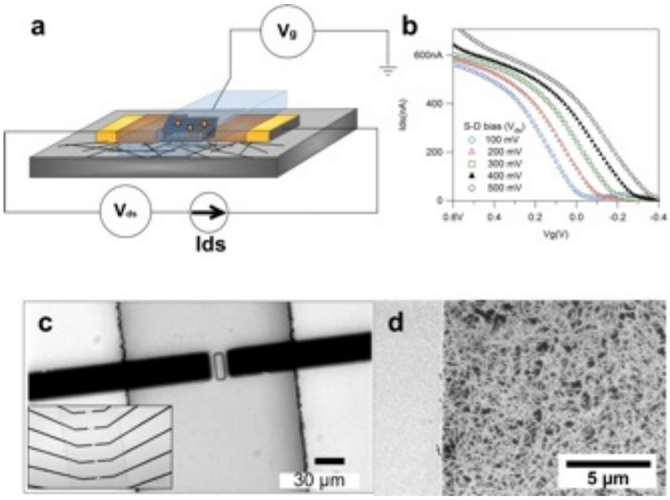

Figure 2 (a) Schematics of experimental device set-up of CNT FET (b) typical p-type depletion curves depending on S-D bias. (c) Micrograph of fabricated devices showing source drain contacts (black) with a window at the gate channel (inset) zoom-out image of arrays of devices (d) SEM image of CNT network.

(IsoNanotubes-S 99%, Nanointegris Inc) were deposited using drop-casting method. The source drain contacts over the CNT networks were deposited by e-beam evaporation, Ti (5 nm)/ Pd (25 nm)/ Au (50 nm), and lift-off process was carried out in acetone sequentially. To isolate metal contacts from electrolyte, lift-off photoresist (PR) (PMGI SF6, MicroChem Corp.) and Shipley S1808 were coated with thickness of 300 nm and 800 nm, respectively. PDMS microfluidic channel were aligned on top of devices for the delivery of solution and samples with dimensions of 400 µm x 50 µm.

B. Lipid bilayer formation and reconstitution of ion channels

1,2-Dioleoyl-sn-glycero-3-phosphocholine (DOPC) powders were dissolved into chloroform followed by solvent evaporation overnight under a nitrogen stream to make the lipid suspension for the vesicle fusion. The dried lipid films were rehydrated in warm 10 mM phosphate buffer (PBS) and sonicated for an hour to make small unilamellar vesicles (SUVs). Finally, the suspension was filtered by a 0.2 µm nylon filter for homogeneous SUVs which helps prevent fouling effect, and improves the quality of SLBs. The filtered lipid suspension was dropped into microchannels lying over nanotube devices and incubated for 40 min at 60 °C followed by rinsing with either DI water or 10 mM PBS to remove unbounded lipid bilayers. To image, DOPCs were labeled with 1 mM fluorescent dyes (Lissamine Rhodamine Red, LR-DHPE) at the molar ratio of 1:1000.

III. Results and discussion

The schematics of device set-up are depicted in Fig. 2 (a). The source and drain contacts (yellow) covered by insulating layer (brown) are laid on CNT networks (Fig.2 (a)). The gate voltage was applied to the electrolyte via a leakage-free Ag/AgCl reference electrode while source/ drain current are recorded. Fig. 2 (b) shows typical p-type I-V responses of the bare CNT transistor in 150 mM KCl solution with different source-drain biases indicating that the device is working properly in aqueous solution with on/off ratio of 600-1300 and transconductance of ~1.2 µS.

Fig.2 (c,d) shows the fabricated device and SEM image of CNT film in the gate area. Prior to deposition of lipid bilayer on the CNT transistor, we have performed deposition test on the bare Si wafer. Fig.3(a) shows a good quality of SLB with continuous film which is confined inside of microfluidic channel. In contrast, poor quality SLB was observed due to the insufficient surface modification (Fig.3(b)). The experimental set up on the inverted fluorescence microscope to investigate the quality of SLBs is demonstrated in Fig.3(c). The fluorescence images of SLB films over the CNT devices is shown in Fig. 3(d). The uniform fluorescence intensity from intensity profile plot indicates that the quality of SLB films is smooth and continuous, and the surface modification was successful to cover the area without defects. In order to evaluate the insulating capability of lipid bilayer, we compared the I-V response of the bare CNT device before and after deposition of pure SLBs.

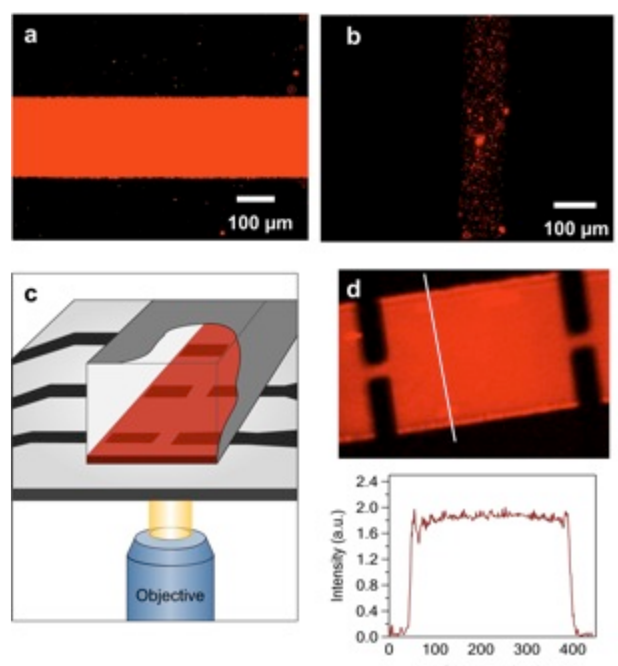

Figure 2 (a) Fluorescence image of good quality of lipid bilayer inside of microfluidic channel (b) poor quality of non-continuous lipid bilayer (c) schematic diagram of device set-up for lipid bilayer formation (d) fluorescence image of lipid bilayer on top of a CNT transistor (bottom) fluorescence intensity profile for the region of while line

In summary, we have demonstrated a semiconducting CNT network-based transistor coated with artificial cell membranes using a microfluidic system. Importantly, the fabrication process to easily deposit and pattern supported lipid bilayers onto CNT devices can be utilized in various applications. In addition, this hybrid device can provide as a sensing platform allows new approach toward low noise nanobioelectronic system that is capable of investigating interactions between biomolecules and electronic devices. With these features, our system could provide a useful tool in bionanosensnig applications.

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