Nano-Electronic Sensors: Chemical Detection Using Carbon Nanotubes

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INTRODUCTION

Since they were first made in 1998,[1] field effect transistors made from semiconducting single-walled carbon nanotubes (NTFETs) have been found to be sensitive to various gases, such as oxygen, ammonia and nitrogen dioxide.[2,3] Such devices, together with devices based on nanowires,[4] have been explored as chemical and biological sensors.

At Nanomix we have used the NTFET as the platform for highly sensitive chemical sensors (Figure 1). We have found that chemical functionalization of NTFET devices makes them sensitive to a variety of inert gases and provides desired selectivity. These NTFETs can be used to create large sensor arrays, and also can be modified for biological detection.[5] Herein, we examine different architectures of NTFET devices for chemical sensing in gas and liquid phases with single-walled carbon nanotubes (SWNTs).

EXPERIMENTAL

NTFET devices were fabricated using SWNTs grown by chemical vapor deposition (CVD) on 200 nm of silicon dioxide on doped silicon from iron nanoparticles with methane/hydrogen gas mixture at 900ºC. Electrical leads were patterned on top of the nanotubes from titanium films 35 nm thick capped with gold layers 5 nm thick, with a spacing of 0.75 µm between source and drain.

RESULTS AND DISCUSSION

The devices were contact-passivated with a liftoff-patterned SiO layer, which was extended over the leads and for several hundred nanometers on either side, as depicted in Figure 2. This geometry was chosen to cover a length of nanotube significantly longer than a few nanometers, the estimated length of the metal-nanotube Schottky barrier. Figure 2b shows the change in a contact-passivated device upon exposure to gases. Upon exposure to gases, the transfer characteristics shifted left (for NH_3) or right (for NO_2), towards more negative or more positive gate voltages. These findings show that the exposed nanotube channel plays an essential role in the nanotube transistor. There has been disagreement about whether gases dope nanotubes directly or modify contacts. We interpret our results as due to charge transfer between the nanotubes and the analytes and dopant layers, involving either electron donors (NH_3) or acceptors (NO_2). Such doping is capable of modifying the device characteristics even when the contacts are covered.

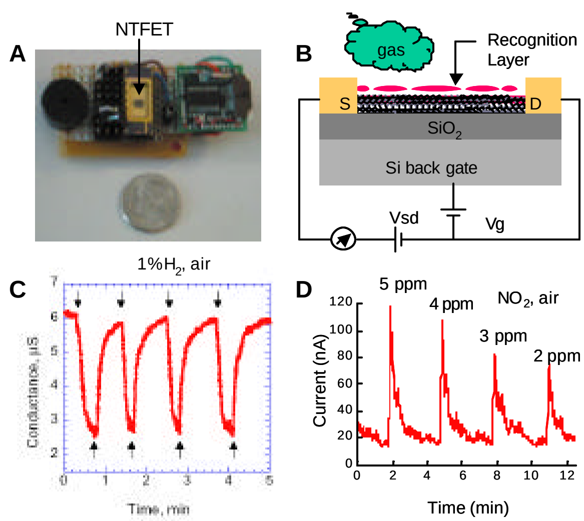

Figure 1. (A) NTFET sensor prototype developed at Nanomix, Inc. (B) Schematic view of NTFET device with a recognition layer specific to gas. (C) Response of a palladium-coated NTFET to four brief exposures to H_2 gas. (D) Response of a PEI polymer-coated NTFET to four brief exposures to NO_2 gas.

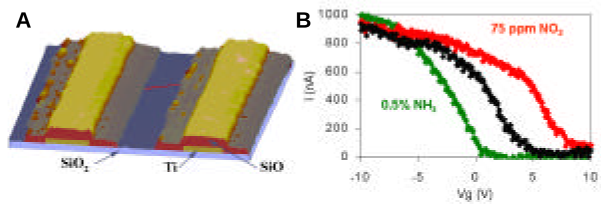

Figure 2. (A) AFM image (2.75 µm) of a contact passivated NTFET device. (B) Isd-Vg dependence for the device in vacuum (center curve), as well as in NH_3 and NO_2 gases.

Interactions of the exposed nanotube channel with different analytes were examined further in a liquid environment. For measurements in liquids NTFET devices can be modified so that the gate voltage is provided by a electrolyte.[6] We have explored chemical sensing in liquids using NTFET devices in both back gate and liquid gate configurations (Figure 3).

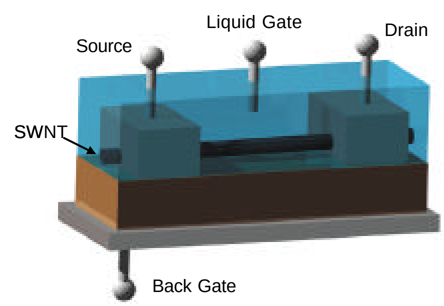

Figure 3. Detection in liquids with NTFET devices by using either back gate or liquid gate configurations.

CONCLUSION

We have shown that the responses of NTFET devices come from interactions of analytes with the nanotube conducting channel. By using NTFETs, interactions of chemicals with SWNTs can be studied and understood. NTFETs can be used in turn as low power, small-size, electronic probes to monitor various chemical processes.

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