Design, Fabrication and Measurement of CNT Based ISFET for NANO Devices

In recent years, there has been increasing interest in monitoring and controlling of pH. It has become an important aspect of many industrial wastewater treatment processes. At the same time, the demand for smaller electronic devices used for various industrial and commercial applications has greatly increased. Micro and nano materials, such as Carbon Nanotubes (CNTs), are well-known for their excellent electrical and mechanical properties, as well as for their small size, therefore they are good candidates to manufacture micro or nano electronic devices. These devices can be used for pH control. However, this cannot be achieved unless CNTs with metallic or semi-conductive band structures can be successfully deposited and separated. In these processes, microchip fabrication and deposition of CNTs using Dielectrophoresis are involved. Besides the application of DEP, an Atomic Force Microscope is used to test the conductivity of Single-Walled Carbon Nanotubes with a conductive cantilever-tip structure. Then, the resistance map and the I-V characteristic curve of a single carbon nanotube can be obtained to describe its electrical properties. Thus, an accurate and efficient approach to verify CNTs metallic or semi-conductive has been achieved.

An ISFET is generally used to measure ion concentrations in solutions; when the ion concentration, such as pH, changes, the current through the transistor will change accordingly. Here, the solution is used as the gate electrode. A voltage between substrate and oxide surfaces arises due to an ions sheath. Actually, an ISFET's source and drain are constructed similarly as a Metal-oxide Semiconductor Field-Effect Transistor (MOSFET). Although an ISFET is very similar to a MOSFET, there are still some differences. As shown in Fig.1, the metal gate is replaced by the metal of a reference electrode, whilst the target liquid in which this electrode is present makes contact with the bare gate insulator. Both of them have the same equivalent circuit. Then, devices with this structure can be applied to pH measurement. However, the objective of this paper is to enhance the inversion layer with CNTs as nano-wire to conduct electrons between the drain and source, the drain current might be much greater under the same gate voltage. And also, the semi-conductive CNTs are able to be fabricated as nano transistor. If that is verified, then we can make these devices compact and cheap earning to CNT’s unique mechanical and electronic properties, such as high current carrying capabilities. As it is known, most of MWCNTs possess metallic conductive properties, while most of SWCNTs do the opposite way. So far, two means of testing conductivity property have been realized successfully.

The first method is Dielectrophoresis (DEP). Polarizable particles, such as CNTs, can be affected by DEP force. Then people can make use of this phenomenon to align CNTs between micro electrodes in certain direction. These micro electrodes can be fabricated by MEMS techniques in HiDEC, ENRC, University of Arkansas. Wire bonding on Au pads are complete by conductive epoxy to apply AC power. When chip is ready, MWCNT stock solution is prepared in DI water with surfactant. A 1.5µl droplet can be deposited on the gap of one pair electrode by pipette. A function generator is used to produce 1.5MHz, 30V p-p AC power. The process can be observed under a camera in microscope. When CNTs droplet disappears, turn off the generator. Thus, a nano-wire forms in between the electrodes. We can measure the resistance of this wire by multimeter. With a DC power supply, we can test its electrical properties. Eventually, an I-V curve is drawn to verify if it is metallic or not.

The other method to measure the electric properties of CNTs is by Agilent 5500 AFM. To make it realized, we need, first of all, a conductive surface to sustain the tubes. In our experiment, a glass slide is coated by an indium tin oxide (ITO) layer on the top, which is conductive. A droplet of SWCNT solution is dropped on the surface and the glass wafer is dried by heating. Then the SWCNT sample is ready for scanning. Agilent 5500 supplies a Current Sensing AFM (CSAFM) function, where an ultra-sharp AFM cantilever, coated with conductive film, probes the conductivity and topography of the sample surface simultaneously. CSAFM requires a special nose cone containing a pre-amp. A bias voltage is able to be applied to the sample while the cantilever is kept as virtual ground. During scanning, the tip force is held constant and the current is used to construct the conductivity image of the surface. It has proven useful in joint I-V spectroscopy and contact force experiments as well as contact potential studies. A CNT stock made up of 0.5mg SWCNTs' powder, 998µl DI water and 2µl Triton is used to provide samples. The solution is also sonicated for about 1 hour to achieve uniformly suspended CNTs. Finally, 20µl from the stock is deposited on the ITO surface to scan. The resonant frequency and force constant of the silicon AFM probes are 13kHz and 0.2N/m respectively. And these probes are coated by Cr/Pt conductively on both sides. The special nose cone assembled has a sensitivity of 10nA/V. Thus, topography and conductivity map are scanned simultaneously with a bias of 200mV, where a single nano tube is found. Then, the cantilever tip is moved about its body and press hard enough to ensure they are in contact. Finally, an I-V curve is drawn after the bias ranges from -3 to 3V.

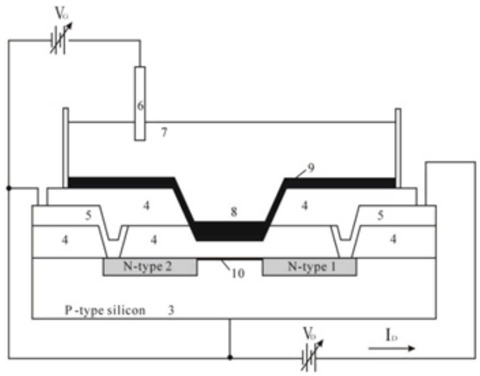

Fig.1. Schematic diagram of a composite gate, dual dielectric ISFET: 1 drain; 2 source; 3 substrate; 4 insulator; 5 metal contacts; 6 reference electrode; 7 solution; 8 electroactive membrane; 9 encapsulant; 10 inversion layer.

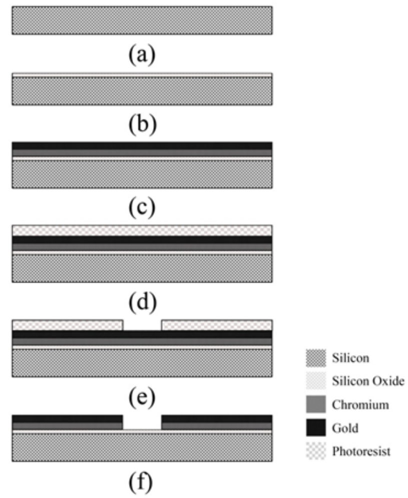

Fig.2. Fabrication process of micro electrode: (a) silicon substrate; (b) 300Å silicon-dioxide by thermal oxidation of silicon wafer; (c) both chromium and gold are deposited on the silicon dioxide surface by evaporation; (d) cover the surface by photoresist layer; (e) photoresist is patterned and exposed; (f) the metals are etched as patterned and the rest of photoresist is stripped off completely.

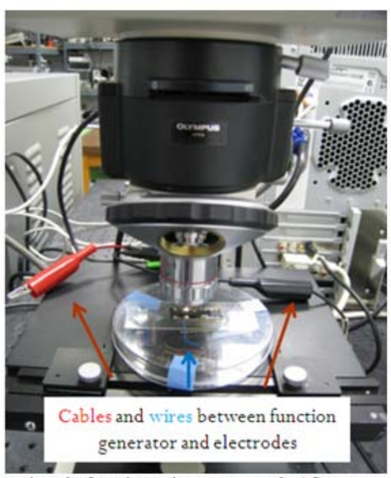

Fig.3. Operation platform in a microscope: apply AC power to a pair of electrode through wires.

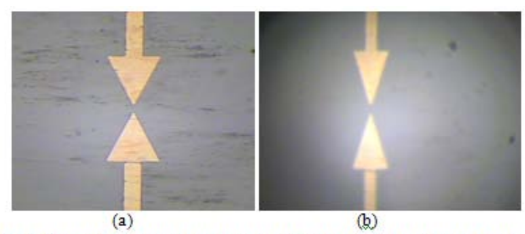

Fig.4. Electrodes observed by the camera: (a) before deposition; (b) after deposition.

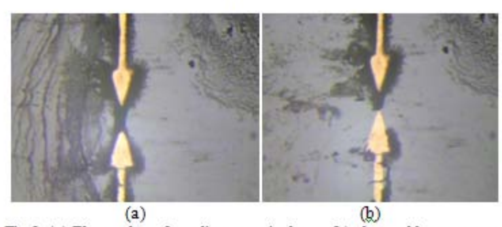

Fig.5. (a) Electrodes after alignment is done; (b) cleaned by acetone.

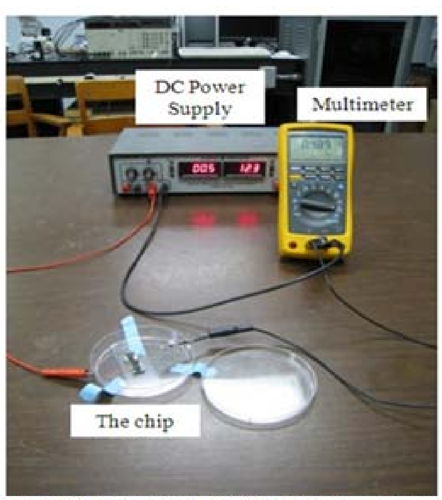

Fig.6. Experimental setup for I-V curve measurement.

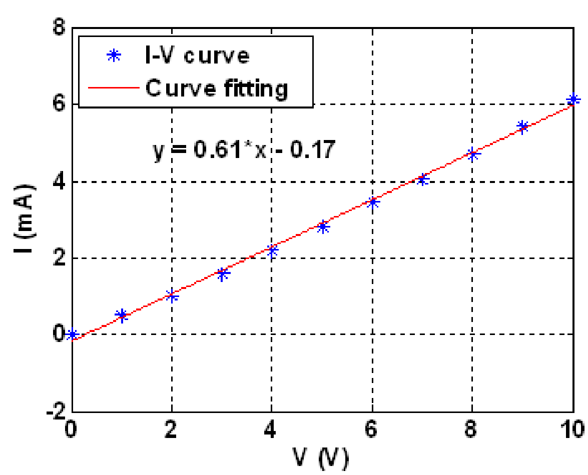

Fig.7. Experimental result of I-V curve characteristic measurement.

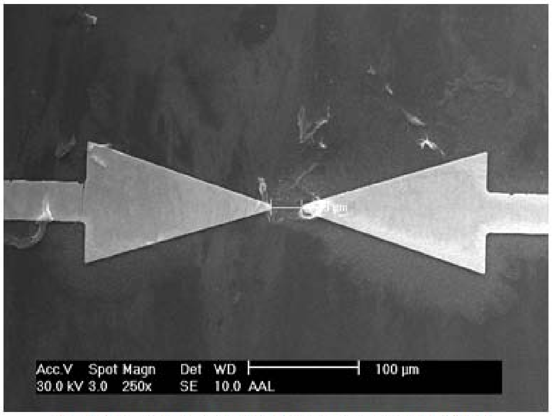

Fig.8. Electrode scanning and gap measurement by SEM.

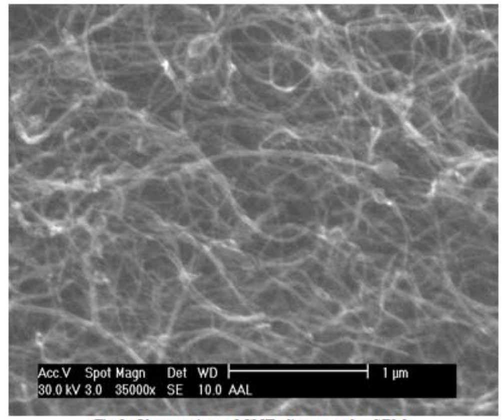

Fig.9. Observation of CNT alignment by SEM.

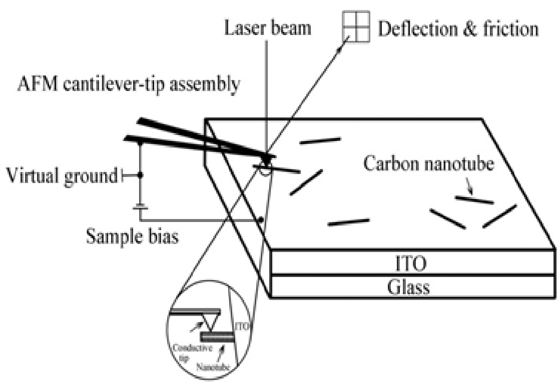

Fig.10. Schematics of electrical properties measurement of SWCNTs through AFM.

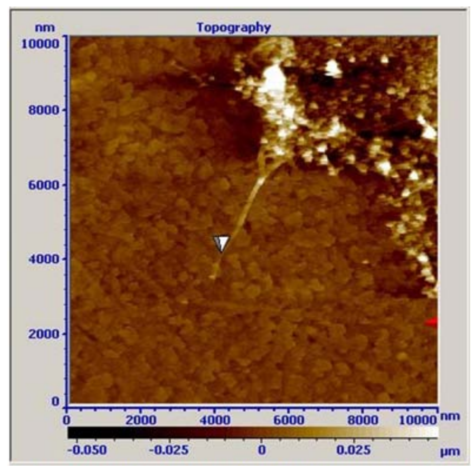

Fig.11. A topography of ITO surface with CNTs sitting on: the position of white cursor is where the probe tip is located to measure.

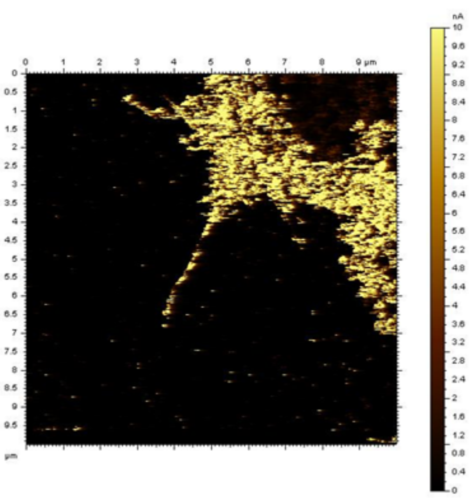

Fig.12. A conductivity map obtained simultaneously with topography at bias 200mV.

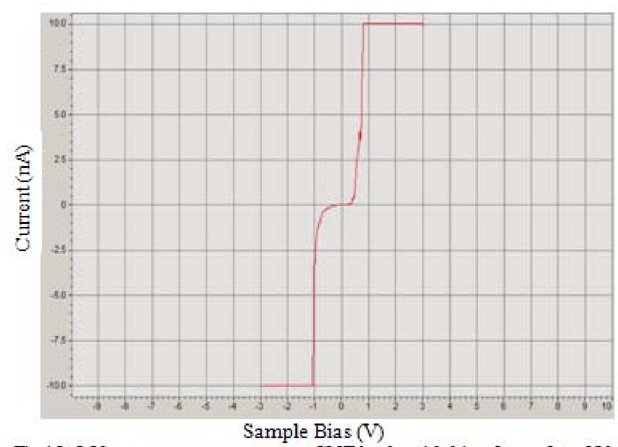

Fig.13. I-V curve measurement on CNT body with bias from -3 to 3V.