# 2. Materials

## 2-1 Commercial single wall carbon nano tube (SWNT)

The single wall carbon nanotube in *N*,*N*-Dimethylformamide (DMF) was purchased from CNI (Carbon Nanotechnologies Incorporation). The diameter of the SWNT is about 1.4nm.

## 2-2 Fabrication of CNT devices (The CNT device was fabricated by ITRI)

A CNT device was fabricated on Si wafer with a 300nm-thick $Si_3N_4$ deposited by Low Pressure Chemical Vapor Deposition (LPCVD) as a gate insulator (Fig. 1).Titanium of 100 nm thickness was sputtered and patterned as source/drain metals. The distance between source and drain is 2 um. The single-walled carbon nanotube was immersed in DMF which was dispersed on the surface of a wafer. The dispersed DMF/CNT solution was sonicated for about 30 minutes in order to prevent the CNT bundling. The CNT, therefore, was arranging on the surfaces with only one CNT or bundle form at random. CNT will stride the source and drain electrode with different angles. After dried at room temperature, 800nm thick photoresist (PR) was patterned as the passivation layer (Fig. 2). The source and drain electrode was protected by PR layer and a sensing window between source and drain electrodes (Fig. 3,4). Therefore, CNT exposed to the air by the sensing window and detect the external substance from the window.

## 2-3 Side-by-side layout and end-to-end layout

We designed two types of CNT devices (Fig. 5). One is the side-by-side layout that has the source/drain electrode distance of 62 μm. Another is the end-to-end with source/drain electrode distance of 2μm.

## 2-4 Passivated and non-passivation CNT devices

The passivation layer that has 800nm thick photoresist (PR) was used to protect the surface of the passivated device (Fig. 6). On the other hand, the non-passivated device did not have the protection layer. The electrode directly expose to the ambient air.

## 2-5 Semiconductor parameter analyzer HP4156 (The instrument was supported by Prof. Chen,s Lab)

The Hewlett Packard 4156A Precision Semiconductor Parameter Analyzer is an extremely useful tool for characterizing semiconductor devices (Fig. 7). It has up to four probes that can serve as voltage sources, current sources, voltage monitors, and current monitors. These are designed to be programmed through a menu-driven user-interface. Possible measurements include, I-V curve of a simple two terminal device, Id-Vds-Vg graphs for MOS FETs, switching characteristics of logical gates, etc.

## 2-6 Low-resistivity deionized water

The distilled water has an 18.2 Mohm-cm resistivity. This value is very close to the theoretical resistivity of water (18.248 Mohm-cm for ultra-purity water) and assures that no electrolytic process is ongoing in the solution.

## 2-7 Variant concentrations of NaCl solution

NaCl is a strong electrolyte. It can be completely ionized when dissolved in the distilled water, and no neutral molecules are formed in solution. Therefore, the NaCl is one hundred percent (100%) ionized in distilled water. These solutions conduct electricity due to the mobility of the $Na^+$ and $Cl^-$. Here, the different concentrations of NaCl solution were allocated by diluting. The concentrations were 1M, $1x10^{-2}$M, $1x10^{-4}$M and $1x10^{-6}$M, respectively.

# 3. Methods

## 3-1 Experiment setup with two-terminal method in ambient air

The passivated CNT device was measured by HP4156, without addition of sample (distilled water and NaCl solution) into the sensing window (Fig. 8). The experiment was measured by two-terminal method. Two probes of the analyzer directly contact to the source and the drain electrodes. A voltage was provided on the drain probe. The measuring current was detected by the source probe of the analyzer. There are not any molecules to change the environment of the CNT. The aim was to explore the basic property of the CNT device in ambient air.

## 3-2 Experiment setup with two-terminal method in aqueous solution

The distilled water and different concentration of NaCl solution were injected into the sensor window with a micropipette. The volume of solution was approximately 0.5μl, which was enough to cover the surface of the CNT in the sensor window (Fig. 9). The conductance of two different solutions was measured with two-terminal method (Fig. 10). The experiment will present the basic characteristic of the device in the aqueous solution by two-terminal conduction.

## 3-3 Experiment setup with liquid-gate electrode in aqueous solution

The conductance through the tube in aqueous solutions was measured by an additional liquid gate (Krüger et al., 2001; Rosenblatt et al., 2002). The voltage, Vg

(-1.5V < Vg < 1.5V), was applied to the liquid-gate to establish the electronic potential in the solution relative to the device (Fig. 11).

## 3-4 Experiment setup with non-passivated devices

In order to compare the leakage current changes between the passivated and the non-passivated device, the non-passivated device measurements were performed under the same measurement condition as that in the experiment setup with liquid-gate electrode in aqueous solution (Fig 12). The non-passivation device is not any CNTs bridging the source and drain electrodes.