The Alignment of Carbon Nano Tube between Aluminum Electrodes using AC Dielectrophoresis Method

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***Abstract*- This paper presents the recent development and fabrication of carbon nanotubes (CNT) based on electrical devices. The silicon oxide is formed by dry oxidation and the Aluminum (Al) layer is deposited using Thermal Evaporator. The electrodes pad act as a bridge for CNT alignment. Then, this single-walled carbon nanotubes (SWNTs) was suspended in isopropyl alcohol (IPA) and Dichloromethane (DCM) solution in ultrasonic condition around 1 hour continuously. Then, the aligment of the CNT was carried out using AC dielectrophoresis and DC electrophoresis method.**

Keywords: CNT, DC electrophoresis method, AC dielectrophoresis method

I. Introduction

The recent discovery of the CNT has attracted considerable attention due to their dimensions and structure sensitive properties. The high electrical conductivity of these nanoparticles allows the utilization of CNTs as electrode material and in combination with its strong electrocatalytic activity offer the ability to mediate electron transfer reactions [1,2]. The facility of electron transfer between the electroactive species and the electrode offers great promise for fabricating chemical sensors or biosensors [3,4]. On the other hand, material such as the CNT exhibit different behaviors and properties at the nanoscales (1-100nm). New theories and discoveries have been found in designing and fabricating at these sizes.

Carbon Nanotube (CNTs; also known as buckytubes) are allotropes of carbon with a cylindrical nanostructure. It has been created with length-to-diameter ratio of up to 132,000,000:1 or several nanometers in diameter to tens of nanometers in length number of milli or even micrometers. CNT have become the subject of intense investigation through fabrication process. It was discovered by NEC Corporation of Japan in 1991, Iijima [5] pure male (Sumio Iijima), they have been excessive emphasized nanostructured materials. It contains approximately ~70% semiconducting nanotubes while the metallic is ~30% and the rest is superconducting electron transport.

Nanotubes are members of Fullerenes (Fuller) structural family, which also includes spherical buckyballs. Carbon nanotubes can be made by chemical vapor deposition (CVD), carbon arc methods, or laser evaporation and in accordance with the classification categorized as:

(i) Single-walled carbon nanotubes (SWNTs)

Single wall pipe is a single cylindrical graphite layers nanostructure (with a high aspect ratio), the diameter size distribution range is approximately close to 1 nm; with a tube length that can be many millions of times longer, fewer defects, and higher uniform consistency. It is by a layer of graphene sheet. A typical SWNTs diameter and length is 1-50nm. It is more important variety of CNTs because they exhibit electric properties and are not shared by the multi-walled nanotube (MWNT) variants.

(ii) Multi-walled carbon nanotubes (MWNTs)

MWNTs consist of multiple rolled layers (concentric tubes) of graphite cylinder that are nested like rings of a tree trunk (with an interlayer spacing of 3.4A) [6]. MWNTs contain the graphene layers. Invidual MWNTs in a suspension have been proven to be cytotoxic [7].

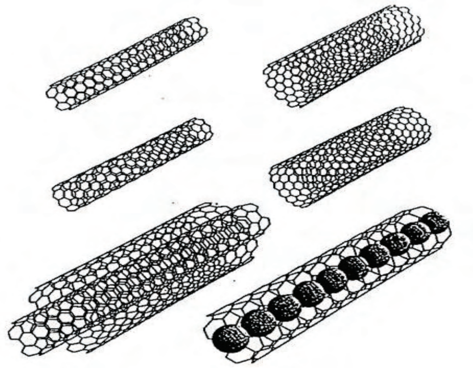


Fig. 1, Conceptual diagram of Carbon Nanotube (CNT) structures including single-walled carbon nanotube (SWCNT), multiwalled carbon nanotube (MWCNT) and metal-atom-filled nanotubes.

II. AC Electrophoresis Method

Recently, some useful and efficient assembly methods have been devised, wherein chemical surface treatment, a magnetic field, or an electric field is employed for assembling CNTs as designed positions [8-10]. AC Electrophoresis method is one of these methods, which uses an electric field, to control the assembly of nanotube bundles between these two electrodes. Various solutions such as isopropyl alcohol (IPA) solution, Dichloromethane solution, Ethanol, Isopropyl Alcohol (IPA) and even Acetone solution used to disperse CNT. The advantages of this method are number of CNT bridging the two electrodes can be controlled by CNT's concentration of the suspension, adjusting the electric field and deposition time. The experimental setup was shown in Fig. 2.

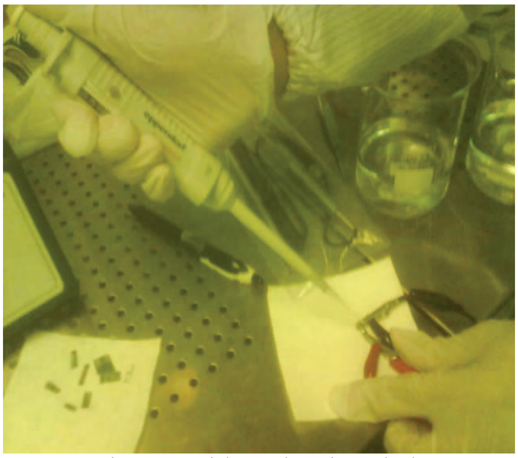


Fig. 2, AC Dielectrophoresis Method

III. Methodology

A, *Mask Specification and Layout Design*

A photomask is employed to fabricate the microgap for CNT aligned based electrical devices. The fig. 3 has shown the photomask that was designed using AutoCAD and then printed onto a chrome glass surface. In this actual mask, there are 160 devices where the length and width for each electrode is 5000µm and 2500µm respectively.

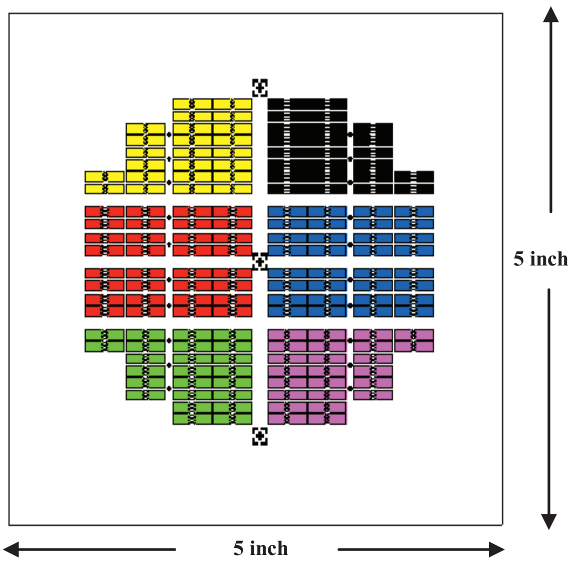


Fig. 3, Actual Mask is used to develop the lateral CNT into microgap

B, *Starting Material*

After the chrome mask was designed and produced, the starting wafer used in this project is a p-type, 100 mm in diameter (4" wafer) silicon substrate as shown in Fig. 4.

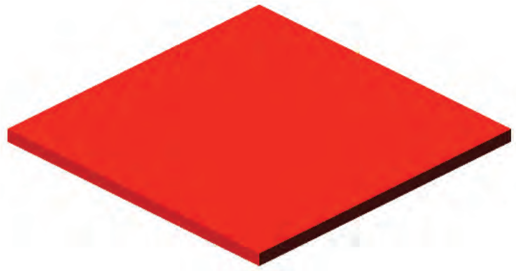
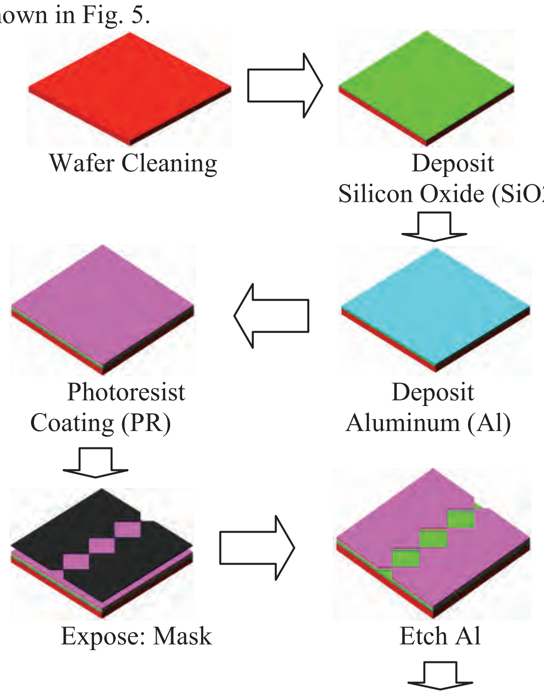


Fig. 4, Silicon Substrate Wafer

C, *Spacer Patterning Lithography*

The process begins with the deposition of 200-500nm layer of silicon oxide (SiO_2) as insulator layer on a clean silicon wafer by modu-Lab Dry Oxidation Furnace. This SiO_2 are deposited by dry oxidation technique before making the proper mask alignment on top of it. After that a thin layer of 400nm Aluminum (Al) layer is deposited. This deposition process was done using thermal evaporator machine. After deposition, positive photoresist (PR) solution was spin coated on Al layer before making the proper mask alignment on top of the PR. The PR layer was coated by Laurell WS-400B-6NPP-Lite Resist Spin Coater. It was followed by soft bake process for 2 minutes for PR maintenance. By using MIDAS MDA-400M Mask Aligner exposure system for 10 seconds (by applying UV light through a mask), pattern from the mask designed is transferred on the PR. Developer solution was used to develop the pattern and then hard/post bake process was run by using hot plate on 110°C for 3 minutes. Finally, aluminum etch solution is used for Al etching. The completed process flow was shown in Fig. 5.



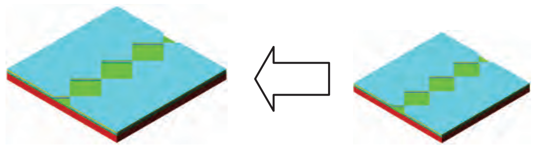


Fig. 5, CNT Electrical Device Process Flow

D, *Ac Dielectrophoresis Method Test Channel*

In this part, Al electrode arrays with 5 gaps of sharp shape, as shown in Fig. 6(a), were used for the electrical contact of CNT between the Al electrode gaps, the distance was 29.6µm. The Single-Walled nanotubes (SWNT) were in powder form purchased from Sigma-Aldrich. The SWNT (0.1µg) were ultrasonically dispersed in Isopropyl (IPA) solution (300ml) about 1 hour in order to unfasten the nanotubes.

The solutions of SWNTs (1.0µl) were dropped on the electrode gap using a pipet. AC (alternating current) electric fields from 4 to 8V at a constant frequency of 20MHz were applied on the electrode for the CNT alignment experiment.

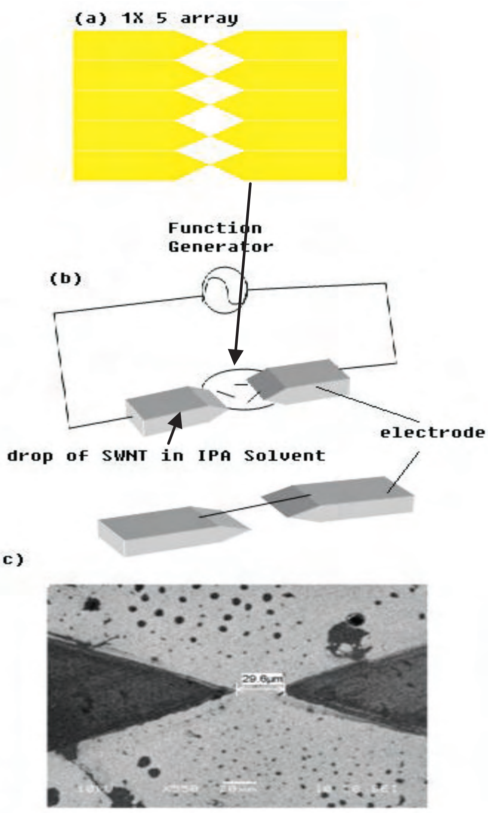


Fig. 6, (a) Optical image of electrode array with 5 sharp-shaped gaps. (b) Schematic of experimental for SWNT assembly across the electrode gap. (c) SEM images of gap on indicated position (29.6µm gap distance, at 4V).

IV. Results And Discussion

In this primary attempt of CNT alignment experiment, the Aluminum (Al) was used as the electrodes. The resulting CNT aligned between Al electrode pads is observed by scanning electron microscope (SEM). The results obtained were not as expected. The CNT did not align between the electrodes as it may be due to Al electrodes gap was over-etched.

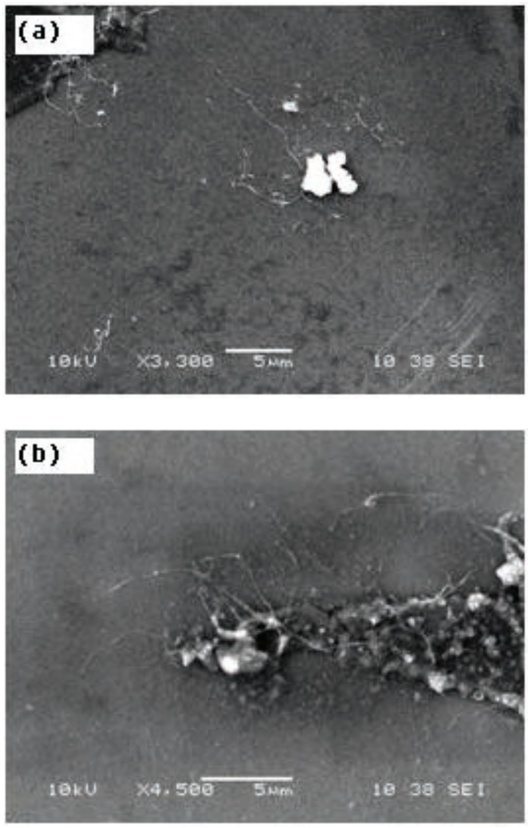


Fig.7, (a) SWNT is well dispersed but not aligned between the electrode pads. It is shown that length of SWNT is very long. (b)Dispersed CNT attracted to the electrodes after AC dielectrophoresis method.

By using the AC dielectrophoresis and the DC electrophoresis method, the experiment was divided into three parts. For the first part, the CNT were dispersed using the Dichloromethane (DCM) solution. During the alignment process, temperature and voltage were varied. From the SEM inspection, it was seen that CNT alignment has better effect under low voltage and high temperature. The DC electrophoresis method was not very effective for CNT alignment process because of the DC signal current flows in one way direction. It produced poorer result compared to AC dielectrophoresis method. On the other hand, the DCM solution does not produce very good CNT dispersion.

In the second part, the AC dielectrophoresis method was used to align the two type of CNT- SWNT and MWNT namely, both at room temperature. Multiple droplets of dispersed CNT solution were dribbled onto the center of electrodes when applying the AC current. As a comparison between the SWNT and MWNT, amount of MWNT is observed to be more attracted towards the electrodes compared to SWNT. This is because of MWNT consist of multiple rolled layers.

Three different solution like Acetone, IPA and Ethanol solution were used in comparison using the AC dilectrophoresis method. As a result, CNT in IPA solution gives a better dispersion solution with compared to the rest of the solutions mentioned. As for the Acetone solution, it was not suitable to be chosen as the dispersion solution because when the dispersed solution was dribbled on the center of electrode pad (applying AC current and frequency), it did not dry up even though heat it on 60°C. On the other hand, IPA and Ethanol solution was fast drying up once the dispersion solution was dropped. The advantage of fast dry up solution is such that it would be easier to perform characterization on a clean and dry device rather than a wet device.

V. Conclusion

This paper summarized on the recent development of CNTs based electrical devices fabrication for electronic and nanosystems sensors. Due to their small size and great electrochemical properties, CNTs continue to attract enormous approach as components in biosensors. Meanwhile, it is now well established that CNT-based electrodes have electrochemical properties that are equal or superior to most other electrodes [11].

Due to their unique properties, CNTs is indeed stimulates the electrochemically DNA biosensing techniques from the immobilization techniques to the detection techniques. Moreover, the chemical modification of CNTs has proven to be an effective way to impart selectivity to the resulting biosensors, which has for instance been exploited for the highly sensitive detection of DNA [12].

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