Development of Strain Sensor Using Carbon Nanotubes Film

Seok-Mo Hong, Hyung-Jin Lee, Tae-Hee Han, Ki-Bong Han, and Yongho Choi

***Abstract*—Carbon nanotube has received great research attentions as a next generation material due to its excellent electrical, mechanical and chemical properties. Using the properties, carbon nanotube is able to improve the sensitivity of bio sensors, gas sensors and mechanicals sensor. When a single walled carbon nanotube is used for the mechanical sensor, a mechanical force deforms the single walled carbon nanotube and changes its electrical properties. The change of electrical properties is due to the change of energy band gap of the single walled carbon nanotube. In this study, we fabricated a strain sensor using single walled carbon nanotubes film. The single walled carbon nanotubes film has 3 dimensional structure of interwoven single walled carbon nanotubes as well as unique properties such as transparency, flexibility and good electrical conductivity. The structure of strain sensor demonstrated in this study is much reliable and convenient for fabrication compared to the sensor with individual single walled carbon nanotubes.**

***Index Terms*—Single walled carbon nanotube, carbon nanotubes film, strain sensor**

I. Introduction

Carbon nanotube (CNT) has great research attentions due to its excellent electrical, mechanical, chemical, and physical properties.[1-5] The CNT has a higher heat conductivity than diamond and has a great tensile strength as young's modulus of 4.5 x 10^{10} [Pa]. Also the CNT has a high specific surface area due to its small dimension and shows active absorption behavior with other chemical species at the surface. Moreover, it permits higher current density than copper and shows a big possibility of using it as electrical conductors. Single walled carbon nanotube (SWNT) can be either metallic or semiconducting material depending on its geometry. During a past decade, the CNT has been a very interesting subject in science and engineering fields and researched to utilize it in electrical, physical and chemical applications.[5-7] The SWNT has a high surface aspect ratio which gives high sensitivity when it is used in bio or chemical sensors. However, the nano-scale dimension of SWNT is an obstacle for device fabrication and the difficulty of modulation its geometry slows down the development in applications.[8-12]

In this research, we fabricate a mechanical strain sensor using SWNTs film. In previous studies, an individual semiconducting SWNT was investigated under mechanical stress.[13] The mechanical deformation on SWNT changed its atomic structures resulted in changing of resistivity. However, it is very difficult to control the structure of SWNT such as chirality which determines its electrical properties. The SWNTs film has 3 dimensional structure of interwoven SWNTs as well as unique properties such as transparency, flexibility and good electrical conductivity. More importantly, the electrical properties of SWNTs are ensemble averaged in the formation. Therefore, the chirality of individual SWNTs can be less considered during the fabrications.

The structure of strain sensor demonstrated in this study is much reliable and convenient for fabrication compared to the sensor with individual SWNTs. Moreover, it is much practical and closer to commercialization.

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II. Experiments

A. Single Walled Carbon Nanotubes Film Synthesis

The details of procedures for synthesis of SWNTs film can be found in REF [14]. The SWNTs used in the device fabrications were grown by the pulsed laser vaporization growth method. Firstly, the as-grown SWNTs were purified by HNO_3. The purified SWNTs were dispersed in surfactant solution which has Triton X-100 surfactant, NaOH, and deionized water. For further dispersion, the SWNTs in surfactant solution were ultrasonicated. The SWNTs in surfactant solution were then vacuum filtered onto a filtration membrane. After the filtration, the SWNTs were deposited in the form of a thin film on the membrane. The thickness of SWNTs film was controlled by the concentration of SWNTs in the surfactant solution and volume of the solution filtered. The film was then transferred onto a substrate by placing the films' side against the substrate. During the transferring, some amounts of pressure were applied on the back side of the filtration membrane. The sample was dried in an oven and then it was found that the SWNTs film was well adhered to the substrate after drying. Finally, the filtration membrane is dissolved in acetone, leaving only the SWNTs film adhered to the substrate.

III. Strain Sensor Fabrication

Fig. 1 shows fabrication procedures of the SWNTs film strain sensor.

First, the prepared SWNTs film was transferred on top of SiO_2 substrate which was thermally grown on Si as shown in Fig. 1 (a). To pattern the SWNTs film, photoresist, S1813, was spin coated, exposed in UV light, and developed in developer. (Fig. 5. (b)). After rinse the sample in DI water, it was put into a plasma etching system and the unmasked SWNTs film area was etched.

Patterning the SWNT films was done by O_2 plasma and the details of patterning procedures using inductively coupled plasma reactive ion etching system (ICP-RIE) was described in REF [15]. In brief, the features of lateral dimension down to ~50 nm were achieved by using electron beam lithography, O_2 plasma, and ICP-RIE system. The major advantage of ICP-RIE system is to control a plasma density and ion energy during an etching process almost independently. Moreover, it is possible to get relatively lower pressure, higher plasma density, larger physical component, more anisotropic patterns, and faster etch rates depending on the system parameters. The several factors of etching SWNTs film were systematically studied. Decreasing the substrate power decreased the etch rates of SWNTs film and photoresist significantly. Decreasing the chamber pressure of ICP-RIE system increased the etch rates of SWNTs film and photoresist, but increased the etch selectivity between the SWNTs film and photoresist which was used as mask during the SWNTs film etching. Also it was found that increasing the chamber pressure did not affect strongly on the etch rates of the SWNTs film and photoresist. Increasing the helium flow rate which was for cooling down the substrate during the etching process did not affect strongly on the etch rates of the SWNTs film and photoresist.

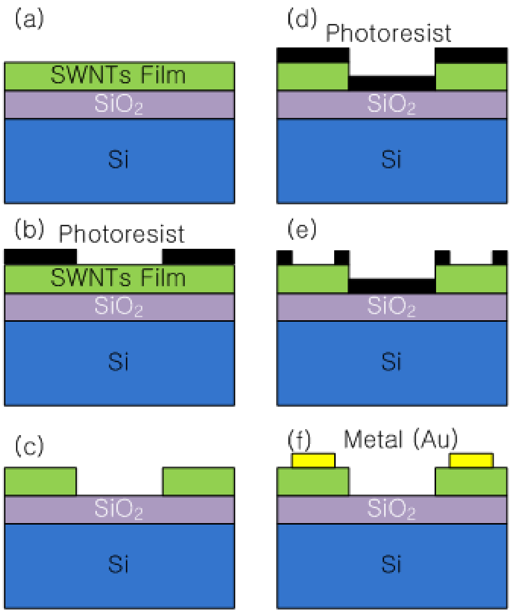

Fig. 1. Fabrication procedures of the SWNTs film strain sensor.

The sample was then dipped into acetone to remove any remaining photoresist. (Fig. 5. (c)) For convenient electrical measurements, metal electrodes were deposited and patterned on the SWNTs film. To deposit metal contacts on the SWNTs film, photoresist, S1813, was spin coated on the sample, exposed by UV light, and developed. (Fig. 5. (d) and (e) Finally, Au metal contacts were electron beam evaporated on the whole sample and lift-off process was subsequently conducted. (Fig. 5. (f))

IV. Results

Fig. 2 is the optical microscope image of fabricated strain sensor using single walled carbon nanotubes film.

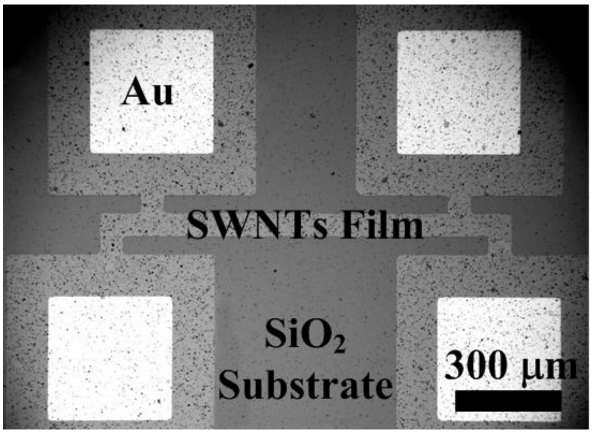

Fig. 2. The optical microscope image of fabricated strain sensor.

The brighter areas are the metal, Au, electrodes and the areas under the electrodes are the patterned SWNTs film. The SWNTs film was patterned 4 point resistivity measurement for relatively more accurate measurements.

Fig. 3 is a schematic diagram of applying strain method on the SWNTs film.

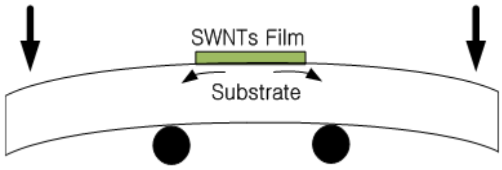

Fig. 3. Schematic diagram of applying strain method on the SWNTs film..

To measure resistivity variations of the SWNTs film as strain sensor, the device shown in the figure was prepared. The top edges of the sample were pressed down by mechanical force in micron scale. Two stainless steel beams were located below centre area of the substrate to support the substrate when the forces on top were applied. Then the substrate was bent down as shown in the figure and the SWNTs film was strained as a result. The current-voltage measurement of the SWNTs film under strain was measured to characterize resistivity measurements. We found a resistivity change of SWNTs film under strain and systematic characterizations are undergoing.

V. Summary

In this study, the strain sensor using SWNTs film was demonstrated. The SWNTs film was prepared using vacuum filtration method and the strain sensor was fabricated using general semiconductor fabrication technologies. The current-voltage changes of the SWNTs film under strain were measured under mechanical strain. The structure of strain sensor demonstrated in this study is much reliable and convenient for fabrication compared to the sensor with individual single walled carbon nanotubes.

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