Aligned Single Walled Carbon Nanotubes for Strain Sensor

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Abstract

Single walled carbon nanotube shows excellent chemical and physical properties and it has been extensively explored for novel applications. It has been shown that single walled carbon nanotube can be used to improve sensitivity of sensors such as bio sensors, gas sensors and mechanicals sensor by its unique properties. As a mechanical sensor, a mechanical force deforms the single walled carbon nanotubes and changes its electrical properties such as resistivity. The deformation results in changing of electrical structure such as band gap of single walled carbon nanotubes. In this study, we fabricate a strain sensor using single walled carbon nanotubes with an efficient structure. The structure contains aligned and multiple numbers of single walled carbon nanotubes to raise sensitivity of the strain sensor. The structure fabricated in this study is much reliable and efficient compared to the sensor with individual single walled carbon nanotube.

Keywords: *Carbon nanotube film, Strain sensor, Sensor fabrication*

1. Introduction

Single walled carbon nanotube (SWCNT) shows unique electrical, mechanical, chemical, and physical properties and has received great research attentions for novel applications.[1-7] It has been shown that SWCNT has excellent properties such as a high heat conductivity and a great tensile strength as young's modulus of 4.5×10^{10} Pa.[1] Moreover, SWCNT has a large specific surface area from its small dimensions and high aspect ratio results in active absorption behaviors with other chemical species on surfaces. Also, SWCNT permits higher current density compare to copper and it has been explored to utilize it as electrical conductors. The SWNT shows either metallic or semiconducting behavior depending on its geometry.[6] The unique property makes the SWCNT as a very interesting material for developments of novel devices in electrical, physical and chemical applications.[5, 8, 9] Moreover, the high specific surface area of SWNT provides high sensitivities. The properties of SWCNT mentioned above make it as one of the best candidates for future bio or chemical sensors. However, the nano-scale dimension of SWNT is an obstacle for the applications due to difficulties in fabrication. Also, it is difficult to modulate its geometry slowing down the development of devices for the applications.[2, 10-13]

We fabricated a mechanical strain sensor using aligned and multiple numbers of SWCNTs. In previous studies, an individual semiconducting SWNT was investigated under mechanical stress for strain sensor and showed good potentials as a mechanical sensing material.[14, 15] In this study, multiple numbers of SWNTs were used in the devices. The multiple numbers of SWNTs is able to improve the detection limit of the sensor and provide higher sensitivities compared to the individual SWNT sensor. Moreover, the multiple numbers of SWCNTs shows ensemble averaged properties and it does not strongly depend on the properties of individual SWCNT. Therefore, the strain sensor demonstrated in this study is much easier to fabricate.

2. Experiment and Discussion

The fabrication procedures of SWCNTs strain sensor is shown in figure 1. The SiO_2 substrate was thermally grown on Si substrate. To create metal electrodes on the SiO_2 substrate, photoresist (S1813) was spin coated on the SiO_2 substrate and patterned by photolithography as shown in figure 1(a). Next, a metal (Mo) was deposited on the whole substrate by electron-beam evaporation under vacuum. Then, the photoresist remained on the substrate were removed by lift-off process with Acetone with a short period sonication, see figure 1(b). To grow SWCNTs at desired locations, not whole sample, we conducted a patterning of catalysts. Prior to the formation of catalysts, the areas were opened for catalysts deposition by photolithography. The photoresist was spin coated on the whole substrate, see figure 1(c) and then patterned by photolithography as shown in figure 1(d).

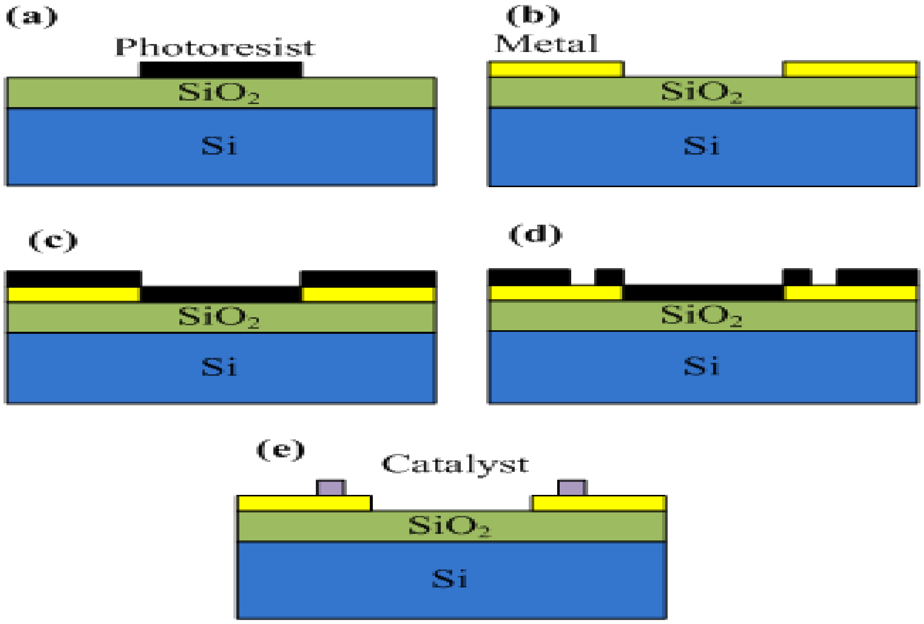

Figure 1. Fabrication Procedures of SWCNTs Strain Sensor.

Finally, catalyst nano particles were spin coated on the whole substrate followed by the lift-off process to remove the remained photoresist. The schematic diagram of the fabricated sample is shown in figure 1 (e). The sample was used for the growth of SWCNTs.

Figure 2 shows the growth system used for the SWCNTs. The system is a general chemical vapor deposition system with extra devices for electric field assisted growth. To grow SWCNTs, the sample was placed into the 1 inch quartz tube. The Mo electrodes on the sample were connected to positive and negative terminals of power supply as shown in the figure. The power supply was outside of the furnace and the wires used were high temperature wires. A 10V was applied to one of the Mo electrode and grounded the other Mo electrode. The furnace was heated up to 900^{o}C with a flow rate of 200 sccm of Ar and a flow rate of 200 sccm of H_2 gases. At the temperature of 900^{o}C, Ar flow was stopped and CH_4 gas was introduced in the tube with flow rate of 200 sccm for 10 mins to provide carbons for the synthesis of SWCNTs. After the actual growth period, CH_4 flow was stopped and Ar gas with flow rate of 200 sccm was introduced in the tube. And then the furnace was cooled down to room temperature and the sample was taken out. The samples were characterized by atomic force microscopy.

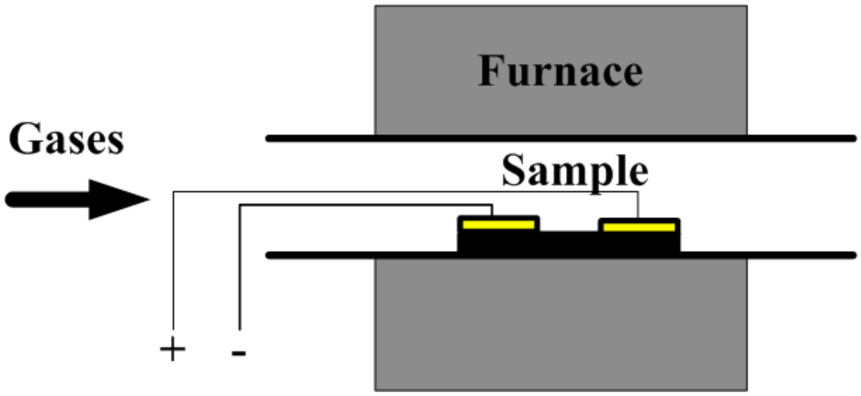

Figure 2. Schematic Diagram of the Growth System. The sample was connected to positive and negative terminal of power supply through high temperature wire.

Figure 3 is the schematic diagram of the fabricated sample (top view) used for the growth of SWCNTs. As shown in the figure, electric field was applied between the catalysts through metal electrodes during the growth period. The main purpose of applying electric field during the growth is that it improves directionality of the growing SWCNTs.[16] Following the direction of applying electric field, the SWCNTs are aligned in one direction. Generally, without the electric field, SWCNTs grown by chemical deposition system are formed in random directions.[17, 18] The random direction of SWCNTs results in the decrease of sensitivity in strain sensors. The SWNTs aligned in one direction in our devices can improve the sensitivity and reliability of the strain sensor.

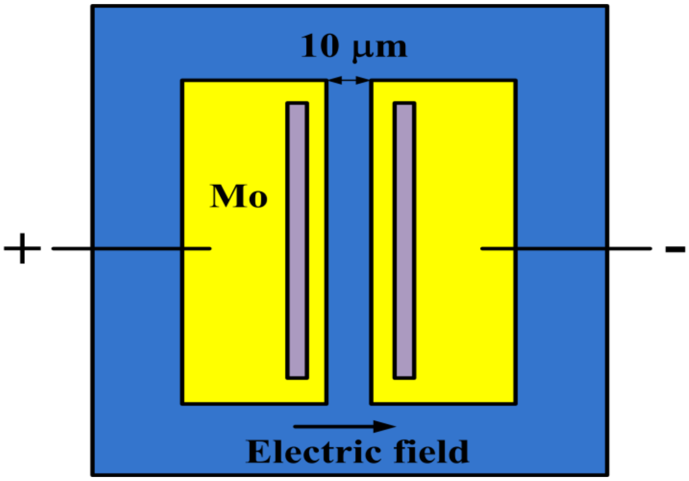

Figure 3. Schematic Diagram of the Fabricated Sample (top view) used for the Growth of SWCNTs

Figure 4 is the schematic diagram of the SWCNTs grown sample. As shown in the figure, multiple numbers of SWNTs are well aligned in one direction and connecting two metal electrodes. To measure the mechanical sensing properties of SWCNTs, the metal electrodes were pressed down. The substrate with the metal electrodes was bent which resulted in the bending of the SWCNTs and straining of the SWCNTs at the same time. The mechanical force was gradually increased and the changes of electrical properties of SWNTs were measured through the metal electrodes using a probe station equipped with an optical microscope. The analysis of the electrical property changes of SWCNTs with strain is in progress.

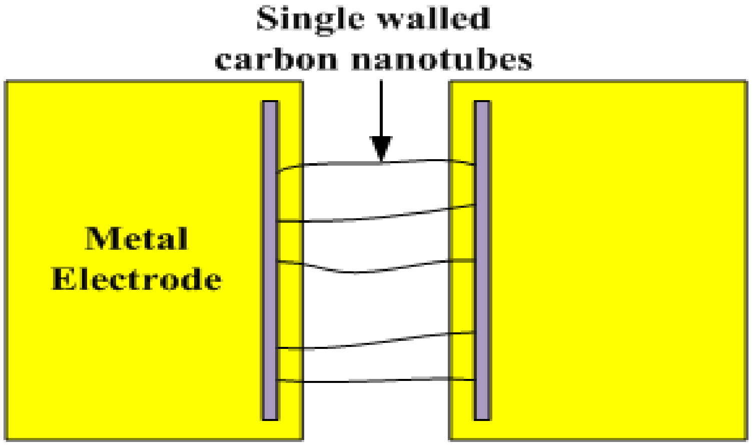

Figure 4. Schematic Diagram of the Sample with Aligned SWCNTs.

The atomic force microscopy image of the grown SWCNTs under electric field is shown in figure 5. The SWCNTs were well aligned in one direction as shown in the figure. We found that not all the SWCNTs were connecting the metal electrodes due to their short length. It is well known that the length of SWCNTs is strongly dependent on the growth time, carbon feed duration. In our experiment, CH_4 gas was supplied for ~10 mins in the system and it should be adjusted to a longer time to increase the numbers of SWCNT connections between metal electrodes. The more connections of SWCNTs should improve the sensitivity and reliability of the devices, strain sensor.

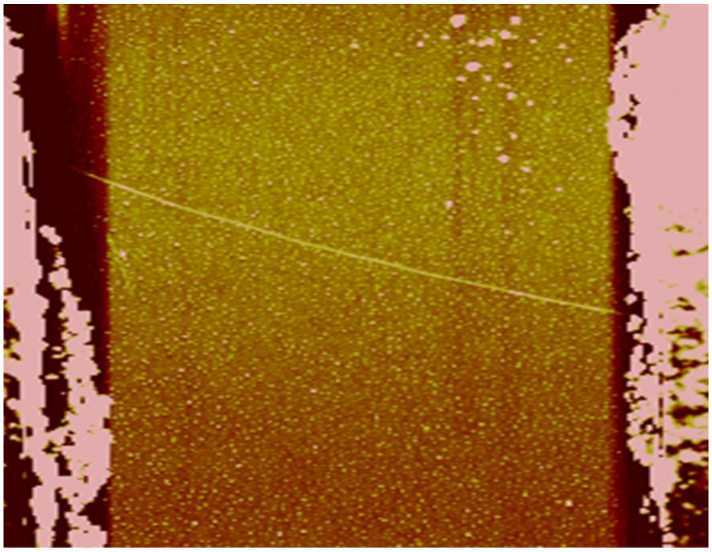

Figure 5. Atomic force microscopy image of SWCNTs under electric field.

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References

[1] Dresselhaus, M., Dresselhaus, G., and Avouris, P.: Carbon Nanotubes: Synthesis, Structure, Properties and Applications. Springer, (2001)

[2] Javey, A., Wang, Q., Ural, A., Li, Y. M., and Dai, H. J.: Carbon nanotube transistor arrays for multistage complementary logic and ring oscillators. Nano Letters 2(9), (2002)

[3] Aguirre, C. M., Auvray, S., Pigeon, S., Izquierdo, R., Desjardins, P., and Martel, R.: Carbon nanotube sheets as electrodes in organic light-emitting diodes. Applied Physics Letters 88(18), (2006)

[4] Appenzeller, J., Knoch, J., Martel, R., Derycke, V., Wind, S. J., and Avouris, P.: Carbon nanotube electronics. IEEE Transactions on Nanotechnology 1(4), (2002)

[5] Bradley, K., Gabriel, J. C. P., and Gruner, G.: Flexible nanotube electronics. Nano Letters 3(10), (2003)

[6] Dresselhaus, M. S., Dresselhaus, G., and Eklund, P. C.: Science of fullerenes and carbon nanotubes. Academic Press, San Diego (1996)

[7] Kim, P. and Lieber, C. M.: Nanotube nanotweezers. Science 286(5447), (1999)

[8] Snow, E. S., Novak, J. P., Campbell, P. M., and Park, D.: Random networks of carbon nanotubes as an electronic material. Applied Physics Letters 82(13), (2003)

[9] Ozel, T., Gaur, A., Rogers, J. A., and Shim, M.: Polymer electrolyte gating of carbon nanotube network transistors. Nano Letters 5(5), (2005)

[10] Fan, Z., Ho, J. C., Jacobson, Z. A., Yerushalmi, R., Alley, R. L., Razavi, H., and Javey, A.: Wafer-Scale Assembly of Highly Ordered Semiconductor Nanowire Arrays by Contact Printing. Nano Letters (2007)

[11] Javey, A., Kim, H., Brink, M., Wang, Q., Ural, A., Guo, J., McIntyre, P., McEuen, P., Lundstrom, M., and Dai, H.: High- k dielectrics for advanced carbon-nanotube transistors and logic gates. Nature Materials 1(4), (2002)

[12] Javey, A., Nam, S., Friedman, R. S., Yan, H., and Lieber, C. M.: Layer-by-layer assembly of nanowires for three-dimensional, multifunctional electronics. Nano Letters 7(3), (2007)

[13] Li, Y. M., Mann, D., Rolandi, M., Kim, W., Ural, A., Hung, S., Javey, A., Cao, J., Wang, D. W., Yenilmez, E., Wang, Q., Gibbons, J. F., Nishi, Y., and Dai, H. J.: Preferential growth of semiconducting single-walled carbon nanotubes by a plasma enhanced CVD method. Nano Letters 4(2), (2004)

[14] Minot, E. D., Yaish, Y., Sazonova, V., Park, J.-Y., Brink, M., and McEuen, P. L.: Tuning Carbon Nanotube Band Gaps with Strain. Physical Review Letters 90(15), (2003)

[15] Yamada, T., Hayamizu, Y., Yamamoto, Y., Yomogida, Y., Izadi-Najafabadi, A., Futaba, D. N., and Hata, K.: A stretchable carbon nanotube strain sensor for human-motion detection. Nat Nano 6(5),

[16] Ural, A., Li, Y. M., and Dai, H. J.: Electric-field-aligned growth of single-walled carbon nanotubes on surfaces. Applied Physics Letters 81(18), (2002)

[17] Adhikari, A. R., Huang, M. B., Wu, D., Dovidenko, K., Wei, B. Q., Vajtai, R., and Ajayan, P. M.: Ion-implantation-prepared catalyst nanoparticles for growth of carbon nanotubes. Applied Physics Letters 86(5), (2005)

[18] Peng, H. B., Ristroph, T. G., Schurmann, G. M., King, G. M., Yoon, J., Narayanamurti, V., and Golovchenko, J. A.: Patterned growth of single-walled carbon nanotube arrays from a vapor-deposited Fe catalyst. Applied Physics Letters 83(20), (2003)

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