FABRICATION OF TRANSPARENT CARBON NANOTUBE FILM PIEZO-RESISTORS

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ABSTRACT

We present the fabrication process of transparent carbon nanotube film (CNF) piezoresistors embedded in polymer membranes. CNFs fabricated by vacuum filtration were patterned on Au-deposited silicon wafer and patterned CNFs were fully transferred into the poly-dimethysiloxane (PDMS) membranes based on the poor adhesion between silicon wafer and Au layer. When the input pressure is applied, the PDMS membrane is deformed, so the resistance of CNFs increases. The gauge factor of CNF with transmittance of 65 ~ 95 % is obtained around 10–20. In polymer MEMS, CNF piezoresistors are the promising materials which were not required the high temperature process.

KEYWORDS: Carbon nanotube film, Transfer method, Embedded transparent piezoresistors

INTRODUCTION

In experimental and theoretical studies, the metallic single-walled carbon nanotubes (SWNTs) and multiwalled carbon nanotubes (MWNTs) have been widely researched as piezoresistors [1, 2], which gauge factor (G) was found about 210 for SWNTs [3] and 78–135 for MWNTs [4]. However, carbon nanotubes (CNT) are still difficult to fabricate as single-tube and large-area devices because of variations in chirality. Recently, carbon nanotube films (CNFs) have been focused as flexible and transparent electrodes in many applications such as chemical sensor [5] and solar cell [6]. Among the various fabrication of CNFs including electrophoretic deposition [7], Langmuir-Blodgett deposition [8], and spin coating [9], vacuum filtration is the best method to increase the film uniformity and control the transparency by changing the amounts of CNT solutions [10].

In this paper, we present a method to fabricate transparent carbon nanotube film (CNF) piezoresistors embedded in poly-dimethylsiloxane (PDMS) membranes for pressure sensing. Patterned CNFs were transferred onto the PDMS using the poor adhesion between Si wafer and Au layer. Applied input pressure deformed PDMS membranes and subsequently increased the resistance of CNF piezoresistors.

FABRICATION

To combine CNFs with the transparent electrode in Micro/Nano device, it is required to transfer CNFs into the polymer substrates. Figure 1 shows the fabrication processes. P-type <100> Silicon wafer was prepared and 200-nm Au layer was deposited by E-beam evaporation. For vacuum filtration, the SWNTs (Iljin Nanotech Co., Ltd, Korea) were dispersed in 1 wt % sodium dodecyl benzene sulfonate (SDBS) solution and sonicated for 15 h, followed by centrifuge process at 2500 g for 2 h. A porous AAO membrane (Whatman International, 20 nm pore size, 47 mm diameter) was used. CNFs were immersed in the NaOH bath to dissolve AAO membrane and rinsed in the DI water. In the water bath, CNFs were transferred into the Au-deposited Si wafer. To form the intimate contact and remove the wrinkle, CNFs were annealed on the 150 °C hot plate. Micro-scale patterns were defined using photolithography process with a positive photoresist (AZ9260, Clariant) and oxygen plasma dry etching at 100 W bias power with the etch rate at ~ 4 Å/s (a). For a thin membrane, 1st PDMS (Sylgard 184, Dow Corning, Inc.) was spin-coated. A silicone tube was connected using uncured PDMS for a circular shape and 2nd PDMS was cured to make a thick substrate (b). PDMS could be peeled off from Si wafer by utilizing the weak adhesion property between Au layer and Si wafer (c). After etching the Au layer, CNFs were fully transferred onto the PDMS (d).

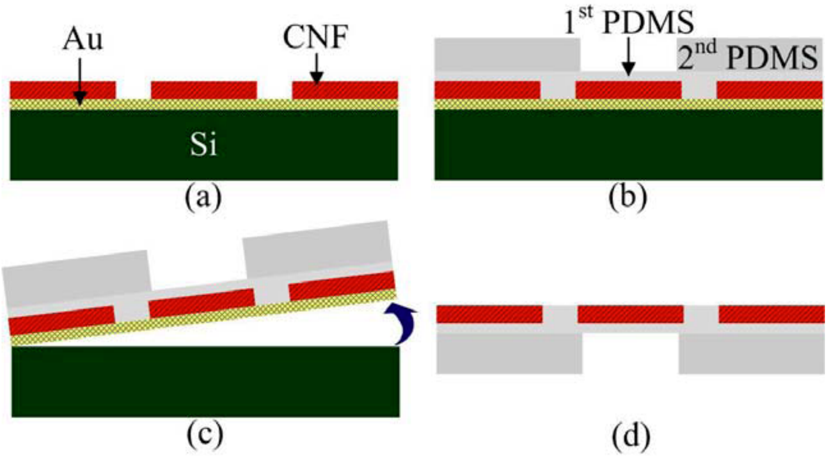

Figure 1: Fabrication processes: (a) patterned CNFs by photolithography and plasma etching on Au-deposited Si wafer, (b) PDMS spin-coating and circular membrane formation using silicone tube and PDMS and (c) peeling off the PDMS using the weak adhesion property between the Au layer and the Si wafer, and (d) fully transferred CNFs after etching the Au layer.

EXPERIMENTAL and RESULTS

To confirm the quality of CNFs as transparent electrodes, the experiments are performed to measure the transmittance and sheet resistance. The transmittance can be controlled by changing the amounts of CNT solutions in the vacuum filtration. For these experiments, various CNT solutions between 50 µL and 700 µL were prepared. Figure 2 shows the transmittance of 65 ~ 95 % at 550 nm which is dominant wavelength in the human eyes and the sheet resistance in the 60–340 Ω/sq range. The inset shows the transmittance of the range of visual and infrared wavelength. These values decrease as the amount of CNT solutions increases during vacuum filtration. Figure 3 shows photo images and schematic view of fabricated results of polymer membrane pressure sensors. This device consists of CNF piezoresistors with 150-µm-width and the circular PDMS membrane with a 130 µm thickness and 2 mm radius

To obtain the gauge factor, the resistance change should be measured as a function of center deflection. The PDMS membrane was deflected with a tungsten probe tip and z-axis micro-stage in steps of 50 µm and the resistance change of CNF piezoresistors with different transmittance was measured using a Keithley 2400 source meter as shown in Figure 4. The resistance of CNFs increases because the contact resistance between CNTs is changed. Therefore the gauge factor of CNFs is obtained in the 10–20 range, which is 2–10 times higher than that of metal. Furthermore CNF piezoresistors are fabricated with low-temperature process, so it is possible to use CNFs as piezoresistors in polymer MEMS. Figure 5 shows the resistance change when the input pressure is applied. In this experiment, the transmittance of CNF was 80% and the thicknesses of PDMS membranes were 110, 130, and 170 µm. Deflection of a thin membrane increases at the same pressure because of the stiffness, which is affected by the thickness of membranes; therefore, the resistance change is greater in a thin membrane.

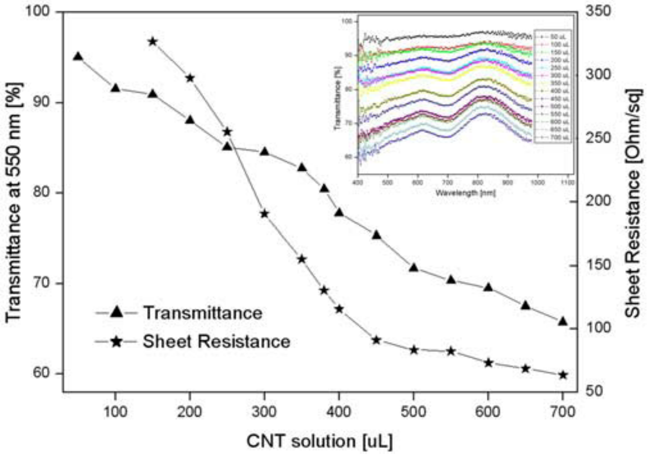

Figure 2: Transmittance (T) of 65–95 % at 550 nm and sheet resistance of 60–340 Ω/sq controlled by the amount of CNT solutions.

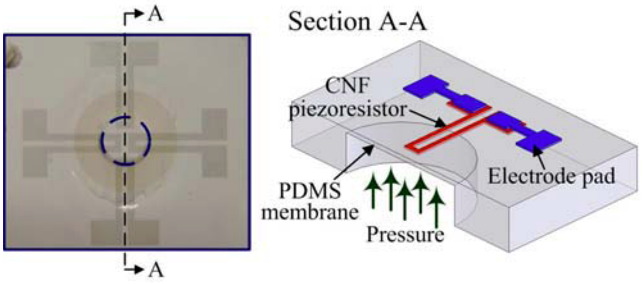

Figure 3: Fabricated results and schematic view of polymer membrane pressure sensor with CNF piezoresistors embedded in 130-µm-thick circular PDMS membranes.

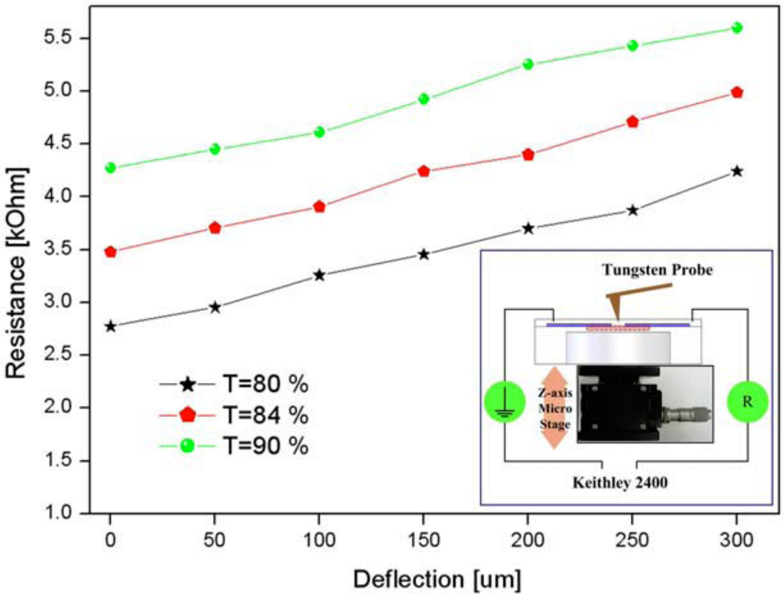

Figure 4: Experimental results of resistance change as a function of membrane deflection to obtain the gauge factor with a different transmittance.

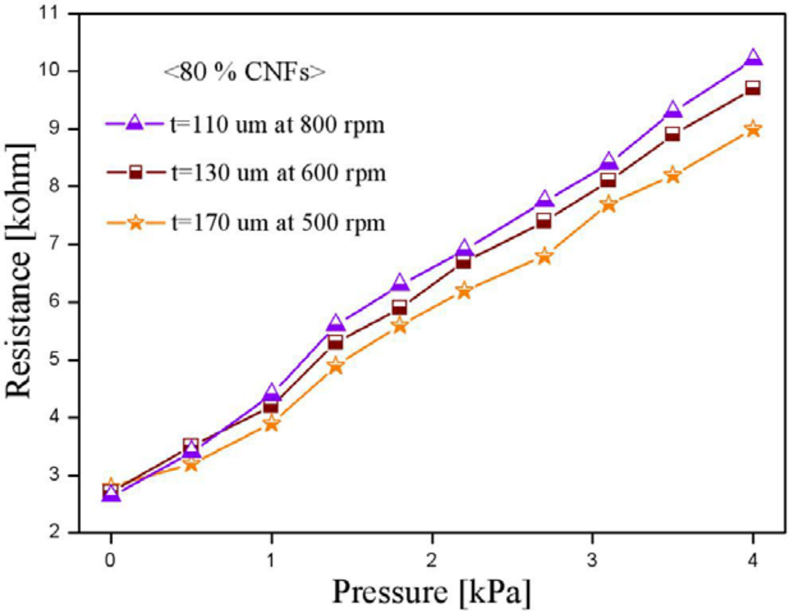

Figure 5: Resistance change by input pressure with a different membrane thickness.

CONCLUSION

In summary, we have confirmed the utility of CNFs as transparent piezoresistors and demonstrated the application of polymer membrane pressure sensors. CNF piezoresistors have many advantages, such as easy and batch fabrication, low-temperature process unlike doped Si piezoresistors, and high-sensitive gauge factor compared to metals. PDMS membranes can be deformed more easily than Si-based membranes because of the low Young's modulus of PDMS as 750 kPa. Therefore, we expect that high-sensitive transparent CNF piezoresistors have great potential in low pressure sensing applications.

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REFERENCES

[1] L. Liu, C. S. Jayanthi, M. Tang, S. Y. Wu, T. W. Tombler, C. Zhou, L. Alexseyev, J. Kong, and H. Dai, Phys. Rev. Lett. **84**, 4950 (2000).
[2] L. Yang, M.P. Anantram, J. Han, and J. P. Lu, Phys. Rev. B **60**, 13874 (1999).
[3] C. Stampfer, T. Helbling, D. Obergfell, B. Schoberle, M. Tripp, A. Jungen, S. Roth, V. Bright, and C. Hierold, Nano Lett. **6**, 233 (2006).
[4] J. Tong, M. Priebe, and Y. Sun, In: Proc. of 20th IEEE Int. Conf. on Micro Electro Mechanical Systems, pp. 843-846 (2007).
[5] J. Oakley, H. Wang, B. Kang, Z. Wu, F. Ren, and A. Rinzler, Nanotechnology 16, 2218 (2005).
[6] M. Rowell, M. Topinka, and M. McGehee, Appl. Phys. Lett. 88, 233506 (2006).
[7] B. Gao, G. Z. Yue, Q. Qui, Y. Cheng, H. Shimoda, L. Fleming, and O. Zhou, Adv. Mater. 13, 1770 (2001).
[8] Y. Kim, N. Minami, W. Zhu, S. Kazaoui, R. Azumi, and M. Matsumoto, Jpn. J. Appl. Phys. 42, 7629 (2003).
[9] M. Meitl, Y. Zhou, A. Gaur, S. Jeon, M. Usrey, M. Strano, and J. Rogers, Nano Lett. 4, 1643 (2004).
[10] Z. Wu, Z. Chen, X. Du, J. M. Logan, J. Sippel, M. Nikolou, K. Kamaras, J. R. Reynolds, D. B. Tanner, A. F. Hebard, and A. G. Rinzler, Science 305, 1273 (2004).

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