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Development of Highly Sensitive Tactile Sensor Using Multi-Walled Carbon Nanotube Arrays

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Abstract

A highly sensitive two-dimensional tactile sensor, which consists of area-arrayed bundles of multi walled carbon nanotubes (MWCNTs), has been developed by applying micro electro mechanical systems (MEMS) technology. The spatial resolution of the developed sensor was 0.5 mm which is superior to that of human finger, 1mm. The change of the electrical resistance of the grown MWCNTs bundles was measured by applying a compression test in the range of 0-30% compressive strain and, the measured strain sensitivity of the developed sensor was 4.8%/%-strain (gauge factor: 4.8).

1. Introduction

The development of future robots used for medical treatment and care nursing has been attracted much attention recently. For the highly reliable operation of these robots, it is very important to detect the state of contact with human body, and thus a highly sensitive tactile sensor capable of measuring pressure and its distribution is demanded. However, there are no tactile sensors that can detect the contact situation with high sensitivity. Therefore, a highly sensitive tactile sensor whose spatial resolution is smaller than that of human fingers (1 mm) and the sensitivity is higher than that of conventional metallic strain gauge (10 mN) is indispensable for these robots.

Recently, many efforts have been made to develop highly-sensitive strain sensors using carbon nanotubes (CNTs). The electronic conductivity of CNTs changes drastically under uniaxial strain because their band structure is changed. In addition, they are deformed easily and have superior deformation flexibility comparing with conventional metals. Therefore, it is possible to develop a highly sensitive tactile sensor using CNTs based on their strain-induced change of the electronic conductivity. The authors have developed a two dimensional tactile sensor using multi-walled CNTs (MWCNTs) by applying MEMS technology [1]. The characteristic of this sensor is a two-dimensional array of vertically aligned MWCNTs bundles formed on a sensor chip with fine patterned interconnections. Since each aligned bundle functions as a sensing element, two-dimensional pressure distribution can be measured.

In this study, deformation characteristics of MWCNTs bundles were investigated by the compression test and we developed a new highly sensitive tactile sensor in which polydimethylsiloxane (PDMS) was used as a protection layer so that MWCNTs bundles deformed easily under axial compressive strain.

2. Deformation characteristics of MWCNTs bundles under compression load

The understanding of deformation characteristics of MWCNTs bundles under the compression load is very important for assuring the stable performance of the tactile sensor because the strain sensitivity is dominated by the deformability of MWCNTs bundles. Thus, the uniaxial compression test was performed repeatedly on the same MWCNTs bundle having a diameter of 100 μm and a length of 100 μm.

Figure 1 shows the deformation of the MWCNTs bundle under compressive loading. In this study, positive value of strain indicates compressive one. When the compressive strain in the range from 0% to 60% was applied, the MWCNT bundle deformed like an accordion, as shown in Fig. 1(b). The compression load at 60% strain was about 1 mN. This accordion-like deformed structure of the bundle was returned to its initial straight shape in the unloading process, as shown in Fig. 1(c). However, the MWCNTs bundle did not recover and showed residual buckling distortion after the unloading when applied

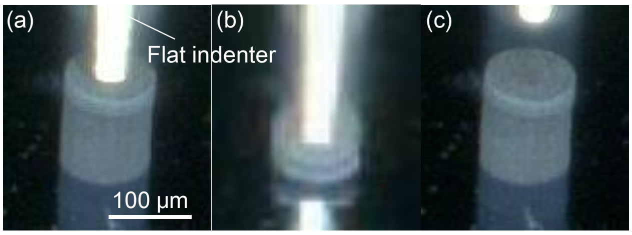

Fig. 1 Deformation of a MWCNTs bundle under compression loading; (a) initial state, (b) 60% compressive strain and (c) after unloading.

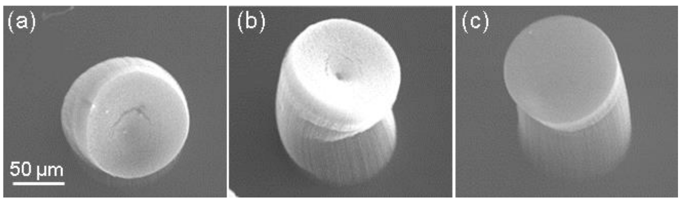

Fig. 2 Residual buckling distortion after unloading when applied compression load (a) 3 mN, (b) 5 mN and (c) 10 mN.

buckling distortion after the unloading when applied compression load more than 1 mN and then compressive strain larger than 60%, as shown in Fig. 2.

Figure 3 shows the compressive stress–strain curve of the MWCNTs bundle. These curves were obtained from the repeated compression test on the same bundle. It is found that compressive stress increases steadily by the applied compressive strain. Besides, the all stress-strain curves are found to have almost the same slope, indicating little change in mechanical properties of the bundle due to the repeated compression. The obtained Young's modulus of the MWCNT bundle was estimated about 140 kPa. Therefore, the deformation characteristics of MWCNTs bundles revealed that they are useable repeatedly in the range of 60%-strain and 1 mN-load.

3. Development of highly sensitive tactile sensor

For improving and stabilizing the sensor sensitivity, the deformability of MWCNTs bundles, which means that they can be deformed easily under compression, is important. Thus, a soft and transparent polymer, PDMS, which does not disturb the deformation of MWCNTs bundles under axial compressive strain, was used as a protection layer of the tactile sensor.

The sensor fabrication process is as follows. Titanium electrodes of 200 µm-width were patterned on a thermally oxidized silicon wafer at period of 300 µm. Iron-nickel catalysts of 6 nm-thick were deposited on the patterned Ti electrodes. A small amount of Al_2O_3 that prevents sintering of the catalyst particles was added to the iron-nickel catalyst layer. After that, the MWCNTs bundles of 20 µm-height were grown on the catalysts by using thermal chemical vapor deposition (CVD) at 750˚C for 1 min. Scanning electron micrographs of MWCNT bundles grown on the electrodes and transmission electron micrograph of MWCNTs are shown in Fig. 4. In order to insulate adjoining bundles electrically, aligned bundles were coated with PDMS and then, upper Ti interconnects were fabricated onto the surface. Finally, whole the sensor surface was coated with PDMS as a protective film. The outlook of the completed sensor is shown in Fig. 5.

The gauge factor of the developing two-dimensional tactile sensor was evaluated by measuring the change in the electrical resistance of the bundle as sensor elements under compressive strain. Measurement temperature was fixed at a constant of room temperature (25ºC +/- 0.1ºC), and the constant current of 5 mA was applied. Figure 6 shows the measured result of the change of the resistance of MWCNT bundles. The initial resistance of the bundle was about 400 Ω. The electrical resistance changed almost linearly with the applied compressive strain and its s gauge factor was estimated about 4.8. This strain sensitivity is higher than twice that of conventional metallic strain gauges. It is concluded, therefore, that a highly sensitive tactile sensor having a spatial resolution of 500 µm and the detection sensitivity of the compressive load higher than 1 mN has been developed successfully.

4. Conclusion

We have developed a highly sensitive tactile sensor by using the stain-induced change in the electrical resistance of MWCNTs and the deformability of MWCNTs bundles under compression.

Reference

[1] M. Ohnishi *et al.*, *Extended Abstracts of SSDM 2014* (2014) 1066.

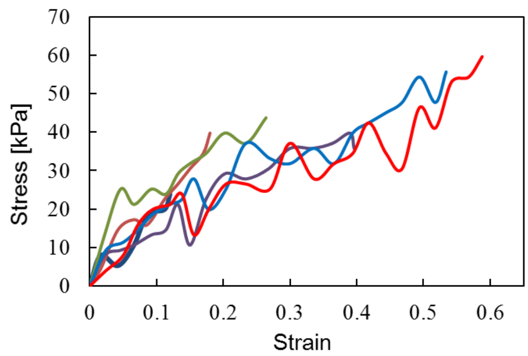

Fig. 3 Stress-strain curve of MWCNTs bundle under repeated compression test.

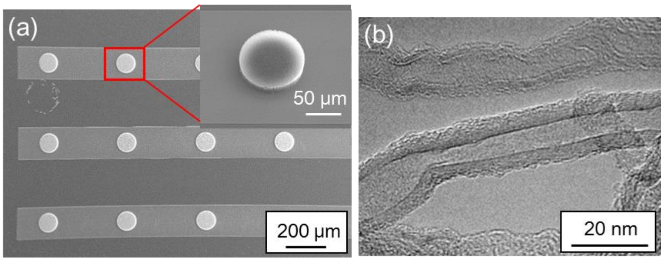

Fig. 4 (a) Scanning electron micrographs of MWCNT bundles grown on Ti electrodes; (b) Transmission electron micrograph of MWCNTs.

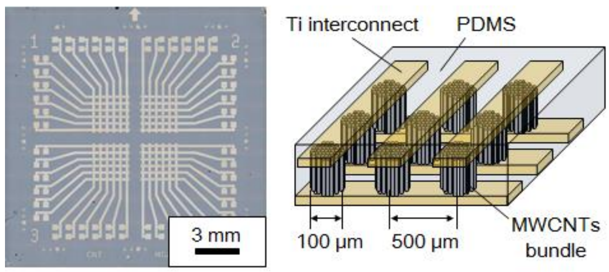

Fig. 5 Outlook of the tactile sensor.

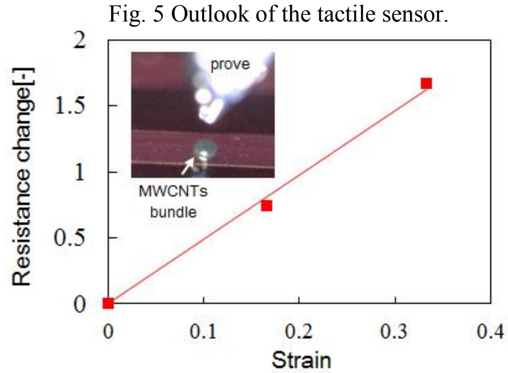

Fig.6 Resistance change of the bundle of MWCNTs under compressive strain.