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Resistance change characteristics of spray-deposited carbon nanotube thin film with bending deformation

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Abstract

Carbon nanotubes (CNT) have characteristics such as high mechanical flexibility, high chemical stability and high electric conductivity. Therefore, a CNT film, a thin film having fibrous network of CNTs, can be used for various applications such as a flexible sheet conductor and sheet heater. Moreover, it can also be applied to displacement and motion sensors that detect those resistance change depending on those bending and stretching. In this study, we examined the resistance change characteristics of the CNT sheets, the thin CNT films supported by resin or rubber sheets, for a purpose to apply the CNT sheets to the displacement and motion sensors. Resistance change of the CNT sheet caused by bending the CNT sheet was examined. The CNT sheets exibited clear resistance changes depending on those bending.

1. INTRODUCTION

Carbon nanotubes (CNTs) have many excellent properties such as high mechanical strength and flexibility, high electrical and thermal conductivity, high chemical stability and so on. Because of these characteristics, CNTs are expected to be used for various fields [1]. Recently, a CNT film, which is a film having fibrous network of CNTs, is intensively studied for a purpose to use it in various application. It is reported that the CNT thin film on flexible substrate is easy to deform (i.e., easy to bend and stretch) and the electrical conductivity also changes depending on its deformation [2]. Therefore, it can be used for various applications such as a flexible sheet conductor and sheet heater. The CNT thin film is difficult to handle itself because of its fragility, so it is usually handled with its supporting material such as rigid silicon substrate, flexible silicon rubber or resin sheet and so on [3]. CNT thin film supported by the flexible sheet (hereinafter called CNT sheet) expands and contracts with the flexible substrate. This behavior is accompanied by a change of electrical resistance. This change can be used for sensing of various motions of human bodies, robots and so on.

In this study, we aimed to apply the CNT sheet to displacement and motion sensors, and examined the electrical characteristics of the flexible CNT sheets. We fabricated the CNT sheets by depositing CNTs by a spray deposition method and forming CNT thin films on silicon rubber sheets. The resistance change of the CNT sheets by the deformation (bending) were examined. We also fabricated the flexible CNT sheets embedded in resin, in which the CNT sheet was entirely covered with thin resin. The resistance change of the resin-reinforced CNT sheet by the CNT thin film by the deformation was examined.

2. EXPERIMENTAL

CNTs used for the CNT thin film formation were synthesized by thermal CVD method using acetylene (C_2H_2) as a carbon source gas. P-type Si (100) wafers with SiO_2 layer (300 nm in thickness) were used as substrates for the CNTs growth. As catalyst layer, Fe (1 nm) film were deposited on the substrates by vacuum evaporation method. The substrate was introduced in the CVD reactor and the CVD was performed for 10 min at 700°C under flow of Ar (120 sccm), H_2 (30 sccm) and C_2H_2 (2 sccm) gases.

The CNTs grown on the substrate were dispersed in ethanol by ultrasonication. After that, the CNT thin film was formed by the spray deposition method on silicon rubber sheet (Fig.1). The size of the CNT thin film is (5 mm × 12 mm). After the deposition, electrodes for the resistance measurements were formed by applying silver paste on both ends of the CNT thin film, and obtained the resistance of the CNT thin film on the silicon rubber sheet by the two-terminal method. The resin-reinforced CNT sheet was fabricated by applying resin (polyvinyl acetate) on the CNT thin film formed on the Si substrate by the spray deposition. After drying the resin, the CNT thin film embedded in the resin was easily peeled off from the substrate (Fig.2). We also measured the resistance value of the CNT thin film embedded in the resin by the same procedure described above. The embedded CNT sheet showed the same conductivity as that before the embedding.

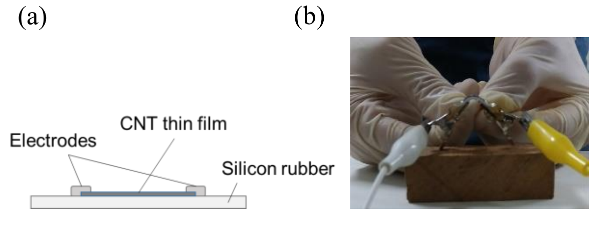

Fig.1. (a) Illustration of the CNT thin film deposited on silicon rubber, (b) Appearance of CNT sheet under bending.

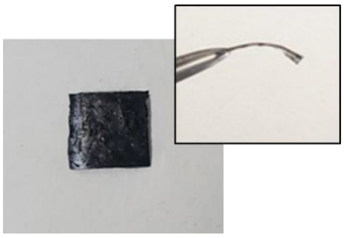

Fig.2. CNT thin film embedded in resin.

3. RESULTS AND DISCUSSION

Fig. 3 shows the change in the resistance when the CNT thin film on the silicon rubber sheet was bent. Here the CNT thin film was formed on the one surface of the silicon rubber sheet. Thus, bending the sheet so that the CNT thin film side becomes the convex surface exerts tensile stress onto the CNT thin film. Conversely, bending the sheet so that the CNT thin film side becomes the concave surface exerts compressive stress onto the surface. The resistance value increases when tensile stress is exerted to the CNT thin film compared with the initial state (without bending). On the other hand, the resistance value decreases when the compressive stress is exerted to the CNT thin film. In both cases, the difference in resistance value is 7 to 8 kΩ. This result shows that the resistance of the rubber sheet with the CNT thin film clearly changes depending on its bending motion. The change of the resistance also depending on the direction of the bending.

Fig.4 shows the dependence of the resistance change of the CNT thin film embedded in resin on its bending. Unlike the result of Fig.3, it shows the increases of the resistance value for both of the bending direction. The resistance increases for the both bending directions and shows symmetric changes as seen in Fig. 4. The difference in resistance value is 5 to 7 kΩ.

We confirmed that the mode of resistance changes for bending direction is different between the CNT sheet with different structure (i.e., the CNT thin film deposited on silicon rubber sheet and the CNT thin film embedded in resin). This difference originates in the difference in the position of CNT thin film in the sheet. The CNT thin film on silicon rubber sheet is formed on the one side of the thick rubber sheet. In this case, the CNT thin film is subject to asymmetric deformation between the two bending directions. This gives rise to tensile and compressive deformation, depending on the bending direction. This bring about the different dependence of resistance on the bending direction (i.e., decrease or increase). On the other hand, the CNT thin film embedded in the resin is placed in the symmetric position in the sheet. Therefore, the CNT thin film is subject to symmetric deformation regardless of the bending direction. This bring about the same dependence of resistance on the bending direction (i.e., increase for both bending direction).

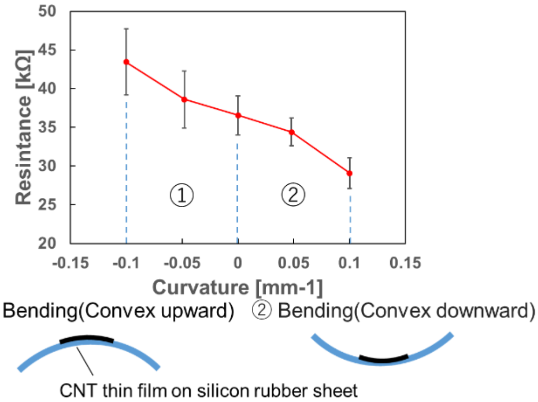

Fig.3. Electrical response of the CNT thin film on the silicon rubber sheet to shape change.

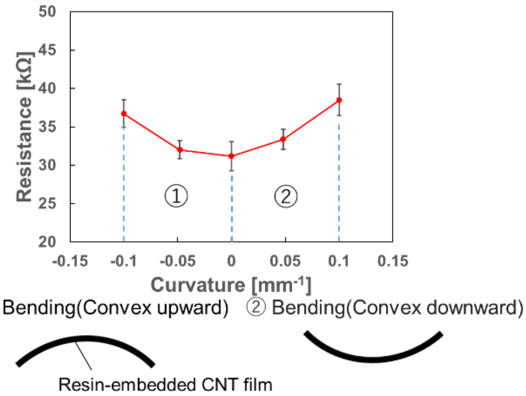

Fig.4. Electrical response of the resin-embedded CNT film to shape change.

4. CONCLUSIONS

We fabricated the flexible CNT sheets and evaluated those response of resistance changes to the bending deformation. We found that the resistances of the CNT thin film clearly responded to the bending of sheet. These results indicate that the CNT thin film is promising for a motion sensor.

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