A Stretching/Bending-Insensitive Flexible Pressure Sensor with Carbon Nanotube-PDMS

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ABSTRACT

We present a flexible pressure sensor based on vertically aligned carbon nanotube (VACNT) carpets on polydimethylsiloxane (PDMS) substrate. The device was fabricated using the partial-embedding of VACNTs in PDMS, which enables the stretchable and flexible device, which maintains consistent electrical resistance with a high level of structural integrity under various strain conditions. The pressure was read measured under an applied pressure applied orthogonally to the sensor. The sensor output under a constant applied pressure was unchanged while applying up to 40% lateral stretching and 180˚ bending, demonstrating a reliable pressure reading independent of lateral stretching or bending.

Keywords: flexible pressure sensor; vertically aligned carbon nanotubes; PDMS; stretchable.

1 INTRODUCTION

Pressure sensing can be obtained using various mechanisms The transduction mechanisms for pressure sensing includes piezoresistive, capacitive, and piezoelectric [1]. For example, piezoresistive pressure sensor translates the resistance change into an electrical signal. Capacitive sensors use the change in capacitance which enables the high sensitivity and low power consumption. Piezoelectric sensors use the piezoelectric effect to generate electrical charges in certain types of solid materials in response to applied mechanical forces.

Flexible pressure sensors have a wide range of applications such as personal electronics, medical and healthcare, automative sensing, and industrial production because of their flexibility and portability [1]. With the integration of multiple flexible sensors, the sensing matrix can be an ideal candidate for skin-attachable electronic devices. There have been extensive efforts in research toward increasing the performance of flexible pressure sensors. The sensitivity of the flexible pressure sensor has been improved by using microstructure with a structure-derived elasticity [2–5] or an interlocking system [6]. The mechanical flexibility of the flexible pressure sensor has been improved by developing unique sensor structures [7–9]. The production cost of flexible pressure sensors has also been improved with the development of facile fabrication technologies [10].

Despite the improvement in sensing performance and flexibility, the pressure measurement under dynamic deformations has remained difficult. If the flexible sensors are used for skin-attachable electronic devices, the sensor can be subjected to various lateral strains via stretching, bending and distortion, while the sensor must gives a reliable pressure sensing under applied pressure orthogonal to the surface. Therefore, a pressure sensor that is insensitive to these lateral strains induced by mechanical deformation (such as stretching, bending, twisting and wrinkling) needs to be developed [8].

In this work, we demonstrate a flexible pressure sensor utilizing vertically aligned carbon nanotube (VACNT) carpets on PDMS substrate, which reliably operates under dynamic deformations of the sensor substrate including stretching, bending, and twisting.

2 EXPERIMENTAL SECTION

2.1 VACNTs Growth Process

We synthesized VACNTs using atmospheric-pressure chemical vapor deposition (APCVD) into carpet-like structures. The catalyst layer consisting of 5 nm Al and 3 nm Fe was deposited on the Si/SiO_2 substrate prepared using physical vapor deposition (PVD). Then the substrate was placed in the atmosphere pressure chemical vapor deposition (APCVD) chamber. The furnace temperature was increased to 750˚C with a constant 500 sccm Ar flow. VACNTs were grown at 750˚C for 15 minutes with 60 sccm H_2 and 100 sccm C_2H_4. Then the chamber was cooled down to the room temperature while maintaining the same

Ar flow rate. The structure of the grown CNTs is vertically aligned in general, while the individual carbon nanotubes are entangled with each other. The morphology of the VACNTs were characterized using scanning electron microscopy (SEM).

2.2 Transfer of VACNTs onto PDMS

To fabricate flexible substrates with embedded VACNTs, we transferred the grown VACNTs onto partially cured PDMS. First, we used a liquid mixture of PDMS base and curing agent (Sylgard 184 Silicone Elastomer, Dow Corning) which were mixed with a ratio of 10:1 to form a PDMS substrate. After degasing under reduced pressure in a vacuum pump, the bubbles were all removed while PDMS was still liquid. Then the liquid PDMS was placed on a hot plate at 65˚C for about 30 minutes before it was fully cured. We optimized the curing condition of PDMS, where the partially cured PDMS was tacky but not fully wet. The grown VACNTs were then placed onto partially cured PDMS. Then the tips of CNTs were partially immersed into PDMS slowly. During the curing process, the embedded CNTs were eventually wetted by PDMS. Then after PDMS was fully cured, the VACNT-PDMS structure was successfully peeled off from the Si/SiO_2 substrate owing to the strong adhesion between PDMS and VACNTs. The entire fabrication process is rapid and facile, which permits the integration of VACNT-PDMS substrate.

2.3 Integration of Flexible Pressure Sensor

Two VACNT-PDMS structures were stacked face-to-face. The application of an external pressure orthogonal to the substrate, deforming the substrate, which enables increased contact of the CNT layers proportional to the applied pressure. The mechanical sensing is enabled by numerous tiny contacts between upper and lower carbon nanotubes. When a deformation is induced by an external pressure (orthogonally applied to the surface), the numerous nanotube-to-nanotube contacts between two VACNT-PDMS structures will increase proportional to the applied pressure, facilitating a decrease in resistance.

2.4 Characterization

The resistance of the flexible pressure sensor was characterized using a Potentiostat. To evaluate the flexibility and durability, we performed both the tensile strain measurements and the bending strain measurements while measuring the resistance. The flexible pressure sensor was stretched up to 40% and bent from 0˚ to 180˚ manually.

3 RESULTS AND DISCUSSION

We applied three different pressure values to the sensor, 1.03 kPa (10g), 1.37 kPa (20g), and 1.82 kPa (50g), respectively. The change of current during loading and unloading was shown in Figure 1.

In addition, various stretching and bending strains were applied to the VACNT-PDMS structure. The substrate of the sensor was laterally stretched to 200% and bent up to 180 degree under a constant pressure applied orthogonal to the substrate. The measured resistance was consistent up to 40% stretching and 180˚ bending as shown in Figure 2 and Figure 3.

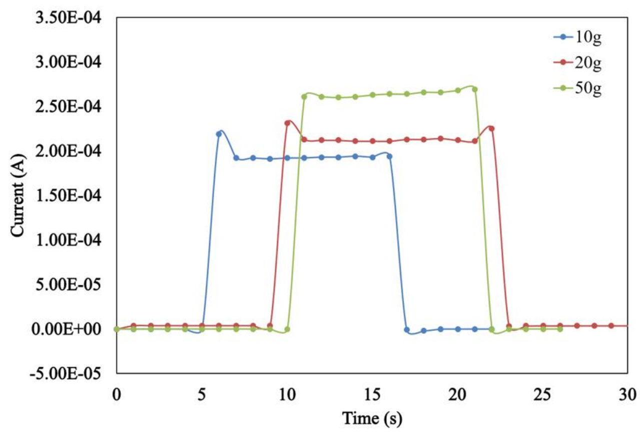

Figure 1: The current change while applying three different pressure values to the pressure sensor, 1.03 kPa (10g), 1.37 kPa (20g), and 1.82 kPa (50g), respectively.

4 CONCLUSION

We have demonstrated a new flexible pressure sensor fabricated using VACNTs on PDMS substrate. The fabricated flexible pressure sensor demonstrated good structural integrity under stretching, bensding and twisting. The measured resistance (thus the eventual pressure reading) was maintained under stretching to 40% and bending up to 180 degree, under a constant external pressure orthogonally applied to the substrate. As next steps, the relationship between applied pressures and the resistance changes will be fully characterized at various levels of stretching and bending at different frequencies under different temperatures and humidity values. The cyclic testing of flexible pressure sensor will also be performed to ensure the durability. The sensitivity will be optimized by patterning the VACNT carpets and tuning the height of VNCNTs. This flexible pressure sensor is promising for applications in various flexible electronics.

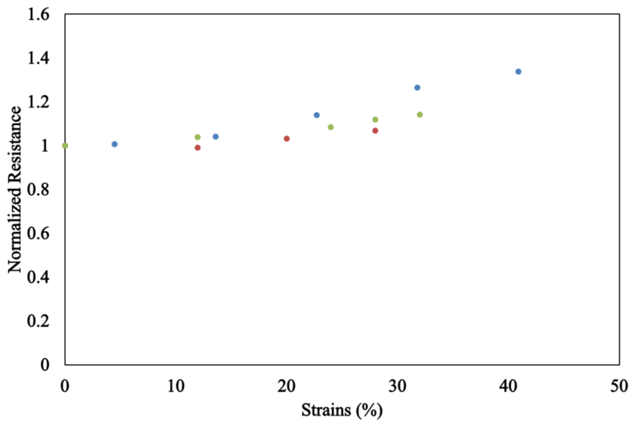

Figure 2: Normalized resistance under stretching strains from 0% to 40%.

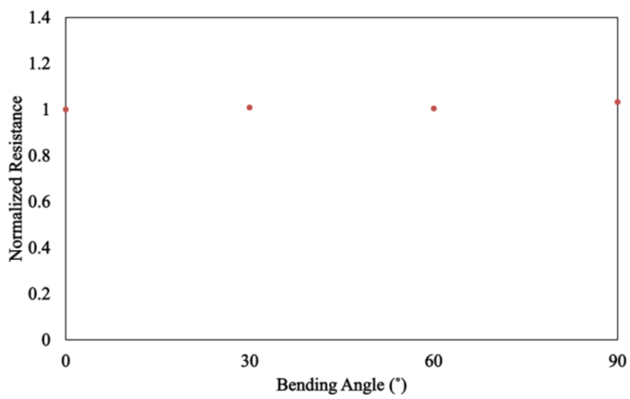

Figure 3: Normalized resistance under bending angles ranging from 0˚ to 180˚.

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