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WATER-RESISTANT SINGLE WALLED CARBON NANOTUBE (SWCNT) BASED STRETCHABLE STRAIN SENSOR

Preety Ahuja, Sanjeev Kumar Ujjain, Radovan Kukobat, Katsumi Kaneko
Center for Energy and Environmental Science, Shinshu University, Nagano, Japan

*Presenting author's e-mail: drpreetyahuja@gmail.com

Introduction

Stretchable strain sensors have fascinated in industrial and academic fields owing to their potential applications in wearable devices, e-skins and human bodily motion detection in movement disorder therapies [1]. Their sensing performance is indeed based on the piezoresistive response i.e. change in resistance in response to applied strain. Sensing materials such as carbon nanotubes (CNT) have been utilized extensively due to their exceptional mechanical, electrical and thermal properties. In order to fabricate strain sensor, CNT composites with polymeric matrix have been realized to enhance their stretchability towards strain tolerance. Different strategies have been utilized to enhance the sensitivity of these fabricated sensors such as generating initial cracks, fabricating thickness gradient film and criss-cross sensing network [1]. However, these strategies suffer from enhanced initial resistance and non-linear response of the sensor, making the calibration process difficult. Furthermore, their performance is also limited as they are not robust enough and are affected by humidity.

In this report, we have utilized newly developed Zn-Al sol gel dispersant for SWCNT bundles developed by our group to embed strongly and stably the SWCNT network in PDMS [3]. We have successfully fabricated superhydrophobic strain sensor with excellent linear response and marked water resiliency under elastic deformations. The good electrical contact between SWCNT and PDMS is demonstrated by in-situ Raman spectra. Besides, the fabricated sensor is capable of detecting very less strain of 0.1% with linear response, endowing highly capable sensor for monitoring structural integrity under harsh conditions.

Materials and Methods

SWCNT (SWCNT, dia. 2nm; Meijo eDIPS) are dispersed by utilizing Zn-Al sol gel to synthesize SWCNT ink as described in our previous report [2]. Desired amount of SWCNT ink was spray coated on glass slide (prior coated with 1% Zn-Al) followed by processing with 3M nitric acid to transfer the SWCNT film on PDMS (4 x 1 cm^2). The electrical connections were made by sputtering gold on the sides of SWCNT film. For fabricating embedded sensor, liquid PDMS is then poured over it leaving 0.5 cm from the sides for making contacts and cured at 75°C for 2.5 hr. Further, it is coated with PDMS-SiO_2 dispersant to generate water resiliency.

Results and Discussion

This newly developed sensor exhibits contact angle of 161.5°±0.8 imparting superhydrophobicity to the sensor, which is consistent even when stretched with 100% strain as shown in Figure 1a. However, sensor without the water-repellent coating showed lesser contact angle (108°±2) and not abile to block the water jet falling on the sensor. On the contrary, no water residue remained on the surface of the water-proof sensor after testing under the water jet, providing the robust water-repellent coating of the sensor.

The sensor was then subjected to 100% strain at 1 mm s^{-1} and the corresponding change in resistance was recorded. The resistance change with strain during loading and unloading follows monotonic and linear increments following the strain path (Figure 1b). This one-to-one correspondence in resistance output with the applied strain makes the device suitable for effectively detecting a strain during infrastructure monitoring. An additional advantage of the present sensor is its high sensitivity to detect lower strains with a fast response. This sensor can detect as little as 0.1% strain and as much as 100% strain with a highly linear and stable response (Figure 1c), even using only the linear relationship between resistance and lower strain (Figure 1c inset). To further apply the sensor to real time application, we have attached the prototype sensor to the forefinger of a glove via adhesive (copper tape) and used it to characterize the motion of a human finger. Our sensor demonstrated a reproducible change in resistance in response to strain applied by finger motion. The bending and relaxing of the finger was sensitively detected, as shown by the increase/decrease in the resistance (Figure 1d), demonstrating its potential efficacy in real applications for wearable devices.

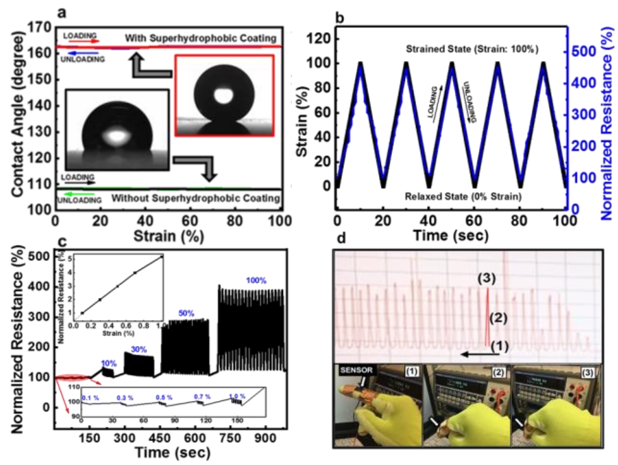

Figure 1. (a) Contact angle variation at different applied strain for sensor with and without water repellent coating, (b) Normalized resitance and strain variation in five consecutive loading-unloading cycles, (c) Normalized resistance change with increasing strain and (d) Real time response of sensor in detecting human finger motion.

Conclusions

We have successfully fabricated superhydrophobic SWCNT embedded strain sensor from well dispersed SWCNT film using Zn-Al sol gel as dispersant. This allows for stretchable networks in PDMS leading to linear increase in resistivity in response to applied large strains (100%) with a highly linear response. This consequently prevented the failure of the electrically conducting network at higher strains, negating the occurrence of non-linear or exponential piezoresistive sensor response, as mostly reported in the existing literature. More importantly, the water resiliency of such a sensor will open many new pathways for a range of applications. We used non-fluorinated chemistry involving SiO_2 and PDMS to generate a water-resilient coating on the sensor, even at 100% strain.

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References

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